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RIEP: Regional integrated energy plan

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Abstract

The energy planning endeavours for a particular region involves the finding of a set of sources and conversion devices so as to meet the energy requirement/demand of all the tasks in an optimal manner. This optimality depends on the objective to minimise the total annual cost of energy and the dependence on non-local resources or maximise the overall system efficiency. Factors such as availability of resources in the region and task energy requirements impose constraints on the regional energy planning exercise. Thus, regional energy planning turns out to be a constrained optimisation problem. This paper describes an optimum energy allocation using integrated energy planning approaches for Uttara Kannada district and makes a satisfying energy allocation plan for the years 2005, 2010 and 2015. Integrated energy planning gives an optimal mix of new/conventional energy sources and is developed based on decision support systems (DSS) approach.

The central theme of the energy planning at decentralised level would be to prepare regional energy plans to meet energy needs and development of alternate energy sources at least- cost to the economy and environment. Regional integrated energy planning (RIEP) mechanism takes into account various available resources and demands in a region. This implies that the assessment of the demand supply and its intervention in the energy system, which may appear desirable due to such exercises, must be at a similar geographic scale. Regional energy planning exercises need to be flexible (to cope with rapidly changing energy systems) and easy to use. The application of DSS is a new approach to this problem. Towards the goal of implementing analytical methods for integrated planning, computerised decision-system provides useful assistance in the analyses of available information, the projection of future conditions, and the evaluation of alternative scenarios. Some of the features of DSS found particularly useful in regional energy planning are: (i) flexible structure—allows appropriate feasible levels of disaggregation, (ii) integrated nature—promotes a better overall understanding of many processes and concepts involved in planning, allowing planners to concentrate on specific energy subsectors, and (iii) iterative nature and easy scenario testing features—provide guidance in optimising data collection activities. Regional integrated energy plan (RIEP) is a computer-assisted accounting and simulation tool being developed to assist policy makers and planners at district and state level in evaluating energy policies and develop ecologically sound, sustainable energy plans. Energy availability and demand situation are projected for various scenarios (base case scenario, high-energy intensity, and transformation, state-growth scenarios) in order to get a glimpse of future patterns and assess the likely impacts of energy policies.

The application of DSS for Uttara Kananda district energy planning focuses on renewable resources that could be harnessed for energy, land use database, sectorwise energy demand database and optimal allocation of energy resources for various tasks, and then explore the energy use consequences of alternative scenarios, such as, base case scenarios, high-energy intensity and improved end use efficiency options. Linear programming formulation for optimum allocation based on the cost minimisation objective shows that there is substantial savings of about 19.19% in energy and 36.24% cost reduction in overall energy system. Cost per unit (kWh) of energy with optimal allocation of energy is Rs. 0.31/kWh (as against Rs. 0.39/kWh without optimisation). Optimisation carried out with the objective of maximisation of efficiency of '*ijk*' combination for all combinations shows energy saving of 19.98% and cost of energy as Rs. 0.34/kWh. The scenario analyses reveal that relatively vigorous growth in energy demand in Uttara Kannada district can be accomplished without exceeding available resources.

Keywords: Integrated energy planning; Decentralised energy plans; Decision support system (DSS); Energy efficiency; Optimisation; Base case scenario; Transformation scenario

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1. Introduction

Energy is essential for economic and social development of a region or a country. However, consumption of fossil fuels is the major cause of air pollution and climate change. Improving energy efficiency and de-linking economic development from energy consumption (particularly of fossil fuels) is essential for sustainable development of a region. The energy sector, on one hand, is a part of the economy and on the other hand it itself consists of parts such as energy supply and energy demand interacting with each other. Both these interactions are of immense complexity. Energy is required for all the economic activities. Energy supplies are essential for both intermediate production as well as final consumption. So, economic development is dependent on the energy system of the country [1]. In turn, the implementation of technologies or improvement of the energy system is dependent on economic factors such as capital costs, energy prices etc. Also, the demand supply balances involve the flow of energy from source as primary energy to service as useful energy. At each stage of the energy flow, technologies are involved with different conversion efficiencies and losses. These complexities and inter-linkages can be understood through a model, which is a simplified representation of reality. A model is a tool for analysis, a method for clarifying the past, understanding the present, and visualizing the future.

Ecologically sound development of the region is possible when energy needs are integrated with the environmental concerns at the local and global levels. Energy planning entails preparation of area based decentralised energy plans for meeting energy needs for subsistence and development with least cost to the environment and the economy [2]. A large number of models have been developed for energy system analysis till date, and which are based on different fundamental approaches and concepts. A classification scheme will facilitate the assessment by providing in the differences and similarities between energy models. Owing to the large number of models, the classification is totally subjective. Some classify the models based only on the analytical approach, i.e. into top-down and bottom up models, whereas some classify them based on the underlying methodology into simulation, optimization, economic equilibrium, etc. Hourcade et al. [3] uses three ways to classify energy models, viz. the purpose of the models, their structure, and their external or input assumptions. Grubb et al. [4] use six dimensions to differentiate energy models, namely top-down vs. bottom-up, time horizon, sectoral coverage, optimization vs. simulation techniques, level of aggregation, and finally geographic coverage, trade, and leakage.

As per the analytical approach, the models can be distinguished as *top-down and bottom-up* models (and also as hybrid models which results from the combination of the two). These two models provide quite distinct results. The differences in outcomes is due to the distinct manners in which these two types of models treat the adoption of technologies, the decision-making behaviour of economic agents, and operation of markets and economic institutions over a given period of time. The *top-down models* use aggregated data to examine the interactions between the energy sector and other sectors of the economy, and to examine the overall macro-economic performance of the economy. This is done by endogenising behavioural relationships. So, top-down models can examine energy policy options concerned with implications for macro-economic indicators and economy-wide emissions. In general top-down models assume that there is no discontinuity in historical patterns, i.e. historical development patterns and relationships among key underlying variables hold constant for the projection period. This assumption is not realistic in the long term, because of rapid population and economic growth. So, top-down models are suitable for predictive purposes only on the short term. They do not explicitly represent technologies and they are based on economic paradigm due to the assumption that the technology-mix results from efficient behaviour by consumer and firms under prevailing economic conditions, i.e. the most efficient technologies are given by the production frontier, which is set by market behaviour. But, the best technologies cannot be determined by market behaviour, because in developing countries predominant technologies are often based on traditional bio-fuels, which are not part of the commercial market. They consider economic sectors at highly aggregated levels and presume the economy to be in equilibrium as a result of optimal decisions taken by consumers, producers and the government. Top-down models provide greater insights into the impacts of economic policy interventions, like taxes or subsidies, which cause market distortions. These models are not realistic for developing countries because a large part of the economy is non-monetary. The macro-economic relationships ignore the influence of extensive but unreported economic activity in the informal and traditional sectors. These models also do not consider the distortions caused by non-monetary economic activities such as firewood collection and use, weak market institutions, persistent market disequilibrium, coexistence of numerous production functions for the same commodity and the limited choices made available to the consumers. Thus, these approaches attempt to capture the aggregate behaviour of the energy sector by use of equilibrium or partial equilibrium models which simulate prices, demand, supply and investment interactions to seek long-term market equilibrium. Such interdependent relationships are at best difficult to quantify and at worst an inaccurate description of the behaviour of markets. This approach is less suitable for economies of developing nations and smaller nations who have little control over the prices of fossil fuels and other raw materials [5].

In contrast, the *bottom-up models* usually focus on the energy sector exclusively, and assume interactions between the energy sector and the other sectors as negligible. So, the feedbacks from the other sectors of the economy remain exogenous to the model. These models use disaggregated data and describe energy supply processes, conversion technologies and end-use demand patterns in detail. Bottom-up models are based on optimistic engineering paradigm that provides an estimate for the technological potential by examining the effects of acquiring only the most efficient existing technologies. But this theoretically predicted potential is unattainable in practice as a result of numerous social, economic (hidden costs, etc.) and legal barriers to the penetration of efficient technologies. These models can be useful in developing countries mainly because they are independent of market behaviour and production frontiers and because technologies are explicitly modelled. But, as the main drivers of the model like demand, technology change, resources remain exogenous to the model; their projections often tend to be too optimistic to be achieved by the internal savings in the economy or even including the inflow of foreign financial investment [6–8]. Hence, bottom-up or disaggregated approach of energy planning is more suitable for developing countries. With this more pragmatic approach of supply and demand, projections and investigations at disaggregated level using available data, local expertise and experiences of the energy system are possible. This approach allows important (and price-independent) effects such as technological innovations, energy transitions, market saturation and other structural shifts to be easily incorporated, which would be virtually impossible using econometric approach. Sometimes, regional macro-economic model is used as the basic framework within which demand and supply projections are made. The economies of developing countries have not reached saturation and they are yet to make most of their investment decisions. They have multiple future investment trajectories to choose from that can significantly

alter their long-term technology-mix, fuel-mix and consumption pattern. Policies with respect to privatization, prices, taxes, trade norms, other regulatory measures, and R&D investments will have a significant impact on the consumption patterns in various end-use sectors and the competitiveness of various technologies over long run. These policies can be analyzed using top-down modelling paradigm. But, the micro-level technology and operational options available in almost every sector of the economy also offer significant scope for improvements in energy-efficiency and economic performance. Bottom–up models are useful for evaluating and implementing these short to medium-term improvement options in technologies, fuels and operational practices. For determining the long-term technology-mix, fuel-mix and resource intensity, the accumulated effects of various short-term investment decisions will be significant.

A range of methodologies is available for modelling energy systems. These include normative (optimising) models [9], system dynamic models and accounting framework simulation models. Models are also classified as simulation, optimization, econometric, macro-economic, economic equilibrium and toolbox models according to the underlying methodology. Econometric methodology use historical data (statistical techniques) to project for short term or medium term. It cannot capture structural change and does not explain determinants of energy demand, since variables are based on past behaviour, a reasonable stability of economic behaviour is required. Compared to this, the macro-economic methodology focuses on the entire economy of a society and on the interaction between the sectors. Input–output tables are used to describe transactions among economic sectors and assist in analysis of energy–economy interactions. The input–output approach can be used only when the assumptions of constant returns to scale as well as the possibility of perfect aggregation hold. These models are often developed for exploring purposes. The effects of inter-temporal preferences and long-term expectations are not taken into account, which results in a rather static representation of technical change [10].

Economic equilibrium methodologies consider the whole of the economy and focus on interrelations between the energy sector and the rest of the economy. It assumes either partial equilibrium or general market equilibrium. Partial equilibrium models focus only on equilibrium in parts of the economy, such as the equilibrium between energy demand and supply, whereas general equilibrium models are concerned with simultaneous equilibrium in all markets, as well as the determinants and properties of such an economy-wide equilibrium [11]. The disadvantage of these models is that they do not provide adequate information on the time path towards the new equilibrium, implying that transition costs are understated.

Simulation models are descriptive models based on a logical representation of a system, and they are aimed at reproducing a simplified operation of the system. A simulation model is referred to as static if it represents the operation of the system in a single time period; it is referred to as dynamic if the output of the current period is affected by evolution or expansion compared with previous periods. This model allows exploring the effects of different hypotheses via scenarios. The impacts of different assumptions and policies can be evaluated by creating different scenarios. The spreadsheet or toolbox model is always discussed as a separate methodology. It is a highly flexible model which is actually more like a software package to generate models than a model per se [12]. They often include a reference model that can be easily modified. The main disadvantage is that all important variables are indicated exogenously as parameters in future scenarios.

Optimization methodologies are used to optimize energy investment decisions or to find the least cost structure of the energy system endogenously. The outcome of an optimization model represents the best solution for given variables while meeting the given constraints. Optimization model assumes that under the given constraints perfect market condition and optimal consumer behaviour prevails. But, in developing countries, a large part of the economy is non-market based. Also a large part of the population in developing countries do not reflect consumer behaviour such as those without access to modern energy, subsistence farmers, slum dwellers, etc. An optimization model can further be distinguished by the mathematical approach used like linear programming, dynamic linear programming, non-linear programming, dynamic non-linear programming, and mixed integer programming. Optimising models typically use linear programming techniques to find out a system configuration that maximises and minimises objective functions (such as minimising costs). These have found favour in applications, such as, least cost of electricity planning and regional energy planning studies. System dynamics model makes use of engineering control theory to simulate a system as a series of interconnected stock and flow variables. System dynamics model is a powerful tool for studying the interrelationships of the different parts of a system, but their behaviour is dependent on the feedbacks between different variables, and of the relationships between those variables. Small errors in estimates of any of these values will tend to be exaggerated as the model is run for a long planning period. These models are normally not applied as practical tools for examining disaggregated energy systems. Most models of disaggregated energy systems have been based on the accounting framework approach. A set of accounting tools is provided to planners for checking the consequence and consistency of a range of scenarios. These accounting tools are simple, and provide emphasis on data, models and an easy-to-use interface.

Stockholm Environmental Institute, Boston developed a multi criteria decision support system long-range energy alternatives planning system (LEAP) to assess policy makers in evaluating energy policies and developing sound, sustainable energy plans [12]. LEAP can be used to project the energy supply and demand situation in order to glimpse future patterns, identify potential problems and assess the likely impacts of the policies. It consists of four program groups: energy scenarios, aggregation, the environmental database, and the fuel chains. LEAP serves as a database, as a forecasting tool, and as a policy analysis tool.

Members of International Energy Agency and Energy Technology Systems Analysis Program developed MARKAL (MARKet ALlocation) a large-scale model intended for the long-term analysis of energy systems at the level of a province, state, country or a region [13]. It is driven by a set of demands for energy services. MARKAL consists of a set of equations and inequations, collectively referred to as the constraints and objective functions, which is usually taken as the total discounted cost of energy system. The important feature of MARKAL is that the model allows the user to set targets and then compute an optional system's response to it.

Baumhögger et al. [14] developed MESAP (modular energy system analysis and planning) a DSS for energy and environmental management on a local, regional, or global scale. MESAP consists of a general information system based on relation database theory, which is linked to different modelling tools. It supports every phase of the structured analysis procedure to assists the decision-making process in a pragmatic way. It offers tools for demand analysis, integrated resource planning, demand side management, and simulation and optimization of supply system. In addition to this MESAP can be used to set up statistical energy and environmental information system to produce regular reports such as energy balances and emission inventories.

Voivontas et al. [15] developed a GIS-based decision support system (DSS) for evaluation of renewable energy sources (RES) potential. RES–DSS was developed in a GIS environment using MAPINFO Professional. A GIS database with data on wind, topography, urban area and special activities have been developed and used for the evaluation of theoretical potential through spatially continuous mapping of RE resources. The evaluation of wind potential is conducted in Crete island by a sequence of steps, which represents sets of restrictions on the exploitation of the potential. In RES-DSS for estimation of wind potential wind speed data necessary for estimation of theoretical potential, are modelled as region objects characterised by the attribute wind speed. Analysis presents high wind potential with wind velocity varying from 6 m/s to over 8 m/s.

Rylatt et al. [16] developed a solar energy planning system to predict and realise the potential of solar energy on an urban scale. The system will support decisions in relation to the key solar technologies: solar water heating, photovoltaics and passive solar gain. The system incorporates a domestic energy model and addresses the major problem of data collection in two ways. Firstly, it provides a comprehensive set of default values derived from a new dwelling classification scheme that builds on previous research. Secondly, GIS tools enable key data to be extracted from digital urban maps in different operational modes.

Regional integrated energy plan (RIEP) is a computer-assisted accounting and simulation tool being developed to assist policy makers and planners at district and state level in evaluating energy policies and develop ecologically sound, sustainable energy plans (Copyright Indian Institute of Science SW2659/2006). Energy availability and demand situation may be projected for various scenarios (base case scenario, high-energy intensity, and transformation, state-growth scenarios) in order to get a glimpse of future patterns and assess the likely impacts of energy policies (http://wgbis.ces.iisc.ernet.in/energy/).

New and renewable energy policy (2005) of the Government of India (http://mnes.nic.in/Policy%20forward.htm) emphasises to augment energy supply to remote and deficient areas to provide normative consumption levels to all sections of the population across the country through new and renewable energy sources in furtherance of the aim of accessibility; and fuel switching through new and renewable energy system/device deployment in furtherance of the aim of conventional energy conservation.

The regional energy planning exercise carried out for Uttara Kannada district based on RIEP involves minimisation of annual cost function to a set of equality and inequality constraints using a linear programming algorithm. The central theme of regional energy planning is the preparation of area based decentralised energy plans for meeting energy needs for subsistence and development with least cost to the environment and the economy. Centralised energy planning exercises cannot pay attention to the variations in socio-economic and ecological factors of a region which influence success of any intervention. Decentralised energy planning advocated these days is in the interest of efficient utilisation of resources, ensuring more equitable sharing of benefits from development. The regional planning mechanisms take into account all resources available and demand in a region. This implies that the assessment of the demand and supply, and the intervention in the energy system which may appear desirable due to such exercises, must be at a similar geographic scale. For example, bioresource assessment of supply and demand at the aggregate level is likely to be misleading as scarcity and surplus is always at a localised level. Consequently, the energy interventions in the form of energy supply enhancement, containing demand and/or encouraging alternative fuels may be aimed at the wrong area or target group. Normally, the district is accepted as the appropriate planning level. However, this leaves behind the complex issue of assigning boundaries for energy interventions. This is due to difference in supply and administrative boundary of a district. The geographical boundaries of the supply system in a region, based on collected biofuels, are determined by the biomass resource base and level of demand within the boundaries. In cases where fuel wood is collected from forests, the quality and accessibility of forest resource base are the most influential factors in determining the boundary of the energy system. Planned interventions to reduce energy scarcity can take various forms, such as

(a) energy conservation through promotion and use of energy efficient stoves for cooking and water heating, compact fluorescent bulbs in place of ordinary incandescent bulbs,
(b) supply expansions through agroforestry, farm forestry and community forestry, and
(c) alternatives—renewable sources of energy such as micro/mini/small hydropower plants and wind, solar and biomass-based systems.

2. Energy planning in India: a review

Integrated energy planning was recognised as an essential element of development planning in India as early as the sixties. The Government of India constituted the Energy Survey of India Committee (ESIC) in 1963 [17] to study ''the present and prospective demands and supplies of energy, both total and in respect of constituents of energy on a national, regional and sectoral basis''. The study was expected to provide the Government with the basic material for development planning in the field of energy up to 1981. The committee was specifically required to look into the energy needs of the rural areas. Keeping in view the past trends in energy consumption, the committee estimated the sectoral and regional energy demands for alternate growth scenarios and provided an analysis of the options available for meeting these demands. The committee also made several recommendations on investment planning in energy sector and pricing of different forms of energy. These recommendations provided the agencies concerned with energy planning in the country a greater insight into the long-term problems of the energy sector.

The Fuel Policy Committee (FPC) was appointed by Government of India in 1970 [18] to prepare an outline of the national fuel policy for the next 15 years. Apart from analysing the supply and demand options in the energy sector, the committee was specifically required to look into the technical and organisational aspects of energy planning with special reference to the scope for improving the efficiency of energy use. While the committee was deliberating on the subject in 1973, the world oil market went through major upheavals making it necessary for the committee to consider the implications of those changes for the Indian economy. In the light of this development, the committee made a number of important recommendations on energy policy including several suggestions on substitution of oil by coal and electricity and on energy conservation in general. The committee adopted econometric forecasting techniques and end use analysis in arriving at sectoral energy demand estimates. However, the major thrust of this study, which was finalised in 1974, was more on supply side of energy than on sectoral demand analysis and demand management.

The Working Group on Energy Policy (WGEP) was another expert group [19] constituted by the Government of India in 1977. WGEP was required to outline the national energy policy for the next 5, 10 and 15 years. The report of WGEP was finalised in 1979. WGEP made detailed projections of the demand for both commercial and noncommercial forms of energy up to the end of the century and suggested a number of corrective policy measures to manage the energy demand. The Reference Level Forecast (RLF) and Optimum Level Forecast (OLF) made by the Working Group highlighted the crucial issues of energy planning relevant to energy conservation and inter-fuel substitution. The methodology adopted by WGEP was more or less similar to the one adopted by its preceding expert groups. The sectoral demand estimates in this report were, however, based on a more detailed analysis of the end use requirements of energy. The recommendations of WGEP provided a broad framework for energy sector planning in the Sixth Five-Year Plan.

Even though both FPC and WGEP emphasised the need for integrated energy planning, in practice however, no formal institutional mechanism could be evolved on a firm footing for examining the various policy issues on an integrated basis. It was in this context that the Advisory Board on Energy (ABE) was set up in 1983 on the eve of formulation of the Seventh Five-Year Plan [20]. In addition to several important recommendations on the technical, financial and institutional aspects of energy, the ABE also made detailed projections of energy demand in different regions till 2004 under assumptions of different macro-economic scenarios. These estimates were made based on both end use and regression methods.

The studies undertaken by ABE and the Expert Groups prior to it provided useful policy guidelines for energy sector planning. However, considering the complexity of the investment choices available in energy and energy related sectors, it became necessary to evaluate the various options together with reference to the long-run economic resource costs involved, so as to provide a more precise indication of the optimum energy strategy to be adopted by the Government. It is in this context that long-term energy modelling studies have been undertaken in the Planning Commission to analyse the supply options available in coal, oil, natural gas and electricity with reference to the economic resource costs involved. The sectoral energy demands in this study were estimated on the basis of anticipated growth elasticities.

These studies emphasised more on resource cost optimisation on the supply side than on sectoral energy demand analysis. It is, however, becoming increasingly evident that a detailed analysis of the factors that contribute to energy demand in different sectors is essential for evaluating the energy implications of different policy options in the economy. This envisages a much more disaggregated analysis of the sectoral energy demands on the basis of end use requirements of energy in each sector. The present study is an attempt in this direction.

3. The decision support system approach

A decision support system (DSS) may be defined as ''a coherent system of computer-based technology (hardware, software and supporting documentation) used by managers as an aid to decision-making in semi-structured tasks''. The characteristics of DSS's [21,22] are

(1) Flexibility and adaptability to accommodate changes in the environment and the decision-making process of the user.
(2) Assist managers in their decision processes in semi-structured tasks-problems for which formal models are useful, but where the planner's judgement is also essential.
(3) Support and enhance, rather than replace, managerial judgement.
(4) Attempt to combine the use of models of analytical techniques with traditional data access and retrieval functions.

(5) Specifically focus on features which make them easy to use by non-computer people in an interactive mode.
(6) Organise data and models around decision(s) and are user-initiated and controlled.
(7) Present information in a flexible way to support the widely differing requirements and cognitive styles of users. To this end, it should be possible to present data in different contexts and formats, and allow the user to change these contexts.
(8) DSS software uses a hierarchical design approach. Rather than attempting to build highly specific software for each study application, the DSS is often designed as a model generator. That is, the model itself is built rather than the model building tools.

From these characteristics, it can be seen that DSS's focus is on providing flexible tools for policy analysis and not on providing models to give answers to structured problems. Indeed, the modelling tools are only one component to DSS, which may be described as comprising three-component subsystems:

(i) *The database management subsystem*: This manages an integrated database to drive all the models. Its purpose is to extract and combine information from a variety of sources, display the data structure to the user in a logical way, and handle personal and unofficial data, so that the user can experiment with alternatives based on personal judgement.
(ii) *The model management subsystem*: The DSS offers the user a number of modelling tools. The capabilities of this subsystem include: creating of new models, cataloguing and editing of existing models, interrelating of models by links through the database and integrating small model 'building blocks' into larger model systems.
(iii) *The dialogue management subsystem*: Some guidelines for the design of this subsystem (the user–system interface) include;
  - the use of a consistent and familiar interface (for example, spreadsheet or word processing programs) throughout the system,
  - help functions which are on-line, extensive and context sensitive,
  - natural language messages, both in normal operation and error conditions,
  - data entry forms ready-filled with sensible default values (profiles or templates),
  - data entry validation,
  - housekeeping functions (data back-ups, copying, deleting files, etc.).

The dialogue style is the main determinant of the usability of the DSS. This design is guided by various methodological considerations, such as

(a) *Scenario approach*: Simulates alternative energy and economic futures under a range of different assumptions, such as, replacement of traditional stoves with improved stoves, switching over from incandescent bulbs to compact fluorescent bulbs, improvement in agricultural pumpsets' efficiency, improvement in industrial machinery's efficiency, agroforestry, etc.
(b) *Integrated energy environment planning*: While emphasising a disaggregated approach, design also stresses the importance of integrating the analyses within a comprehensive planning framework. Integration of all types of

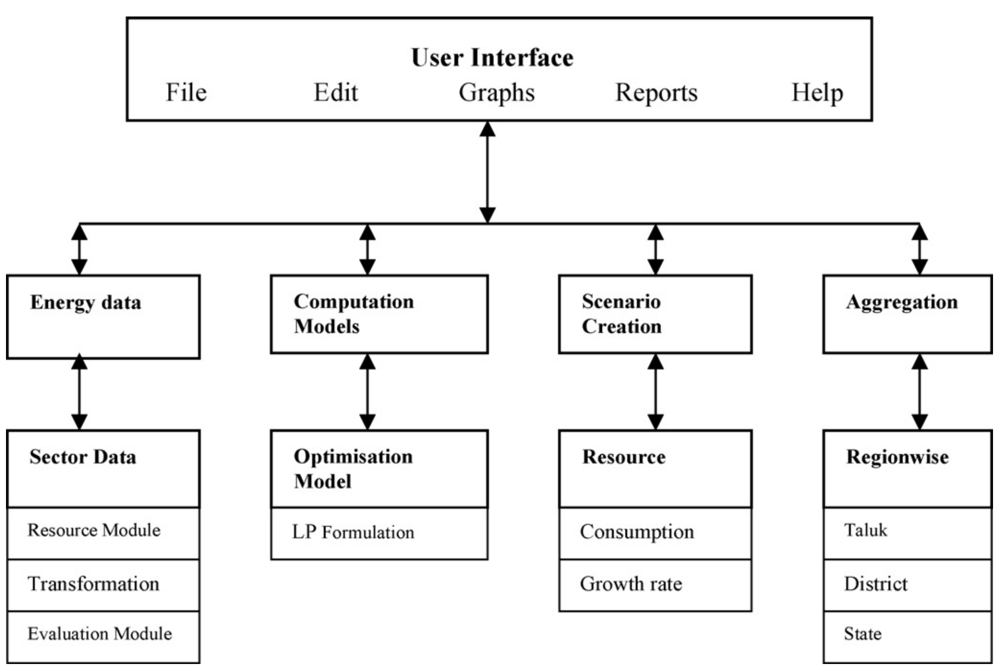


Fig. 1.1. Regional energy planning model structure (overall).

energy sources [23], sectorwise energy demands, intermediate conversions of fuels, primary resources, and environmental and economic impacts across separate geographical areas takes place [24].

(c) *End use, needs driven approach*: Resource requirements and supply side projections are carried out based on energy services required in different economic sectors. This approach places development objectives, such as, the provision of end use goods and services at the foundation of energy analysis. It achieves the goal of integrated energy planning by allowing the development plans of different sectors to guide the evaluation of energy strategies [25].

(d) *Flexibility and user friendliness*: Is designed as a set of modules and is flexible, expandable and comprehensive. These provide an expandable data structure which can be adapted to the diverse energy systems with different requirements and developmental views of planners (Figs. 1.1 and 1.2).

The regional energy planning program, designed based on these concepts, consists of mainly four blocks of programs: energy scenarios, computation models, aggregation and the energy database. This is illustrated in Fig. 1.1.

The energy scenario module addresses the main components of an integrated energy analysis, namely, sectorwise demand analysis, energy conversion and resource assessment. There are three programs for building scenarios (demand, transformation and resource) and one for comparing and evaluating scenario costs and impacts. The planner uses the scenario building programs to develop current energy balances, projections of supply and demand trends, and scenarios representing the effects of energy policies, plans and actions. The aggregation program assembles area level (taluk, district, region, state, nation) energy projections into multi area results. The detailed structure is given in Fig. 1.2 and the individual components of the model are discussed below.

3.1. The energy demand module

This module provides a disaggregated end use approach to analysis of energy requirements. Data is assembled hierarchically into four levels. These are

- **Sectors**: household, agriculture, industry, commercial and transport, and each sector is divided into **subsectors** (e.g., high income, low income, large-scale industry, small-scale industry, etc.). Each subsector is divided into **end uses** (such as cooking, water heating, lighting, irrigation in household sector, etc.), and each end use is divided into **devices** (such as traditional stoves, improved cook stoves, kerosene stoves, incandescent lamps, fluorescent bulbs, pumpsets, tractors, etc.). Driving activities to project future demand is computed

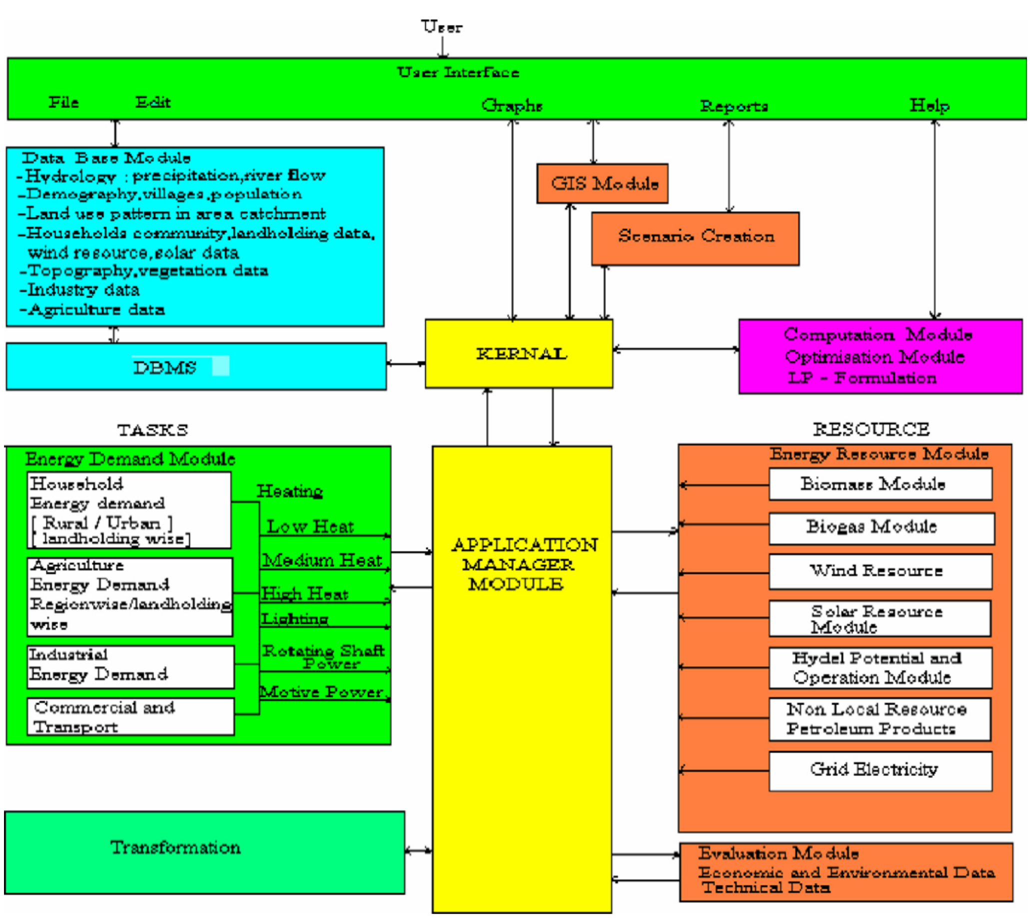


Fig. 1.2. Detailed structure of integrated regional energy planning.

by growth rates, macro-drivers (population), and energy intensity at device level. Demand by devices and sectors are aggregated to get region's demand.

3.2. The transformation module

This module simulates the energy sector conversion processes that turn primary resources to final power. For example, the biomass requirements (for producer gas, electricity, charcoal, etc.) computed by transformation program are used by the biomass resource program to match biomass resource demands to available wood stock and yields.

3.3. The energy resource modules

Various resource modules discussed here are biomass, wind energy, solar energy and hydroenergy available in the region.

3.3.1. The biomass module

The biomass module examines the impact of land use changes on the biomass resource base and the impact of bioresources consumption. This, with wood productivity models/details and land management practice details, is designed to assess the present state of bioresources (includes fuel wood, agricultural residues, horticultural residues, dung and other bioenergy resources) in a region to meet the demand [26,27]. This is outlined in Fig. 1.3.

Areawise biomass requirements are disaggregated to simulate the requirements for wood and other biofuels in the individual sub-areas (taluk) used in the analysis. At the same time, the effects of changing patterns of inter taluk (sub-area) such as from hilly to coastal taluks are incorporated. Wood stock and yield data is assigned to each land type to account for spatial variation in availability of resources. Dung resources are projected through an inventory of animals in each area and the quantity of dung produced per animal in each region. The energy demands for firewood, wood used for charcoal and other biomass fuels are taken from the calculations of the demand and transformation programs. Final demand for charcoal in the demand program is met in the transformation program by a mix of traditional and efficient kilns [28–30].

Projections of available wood resources, combined with estimates of the energy requirement and scenarios describing the land use changes, allow the biomass module to simulate future wood growth and harvest, and indicate the adequacy of wood and other bioresources. In the final analyses, this module computes supply-demand shortfall if resources are found to be inadequate to meet requirements. This supply-demand shortfall

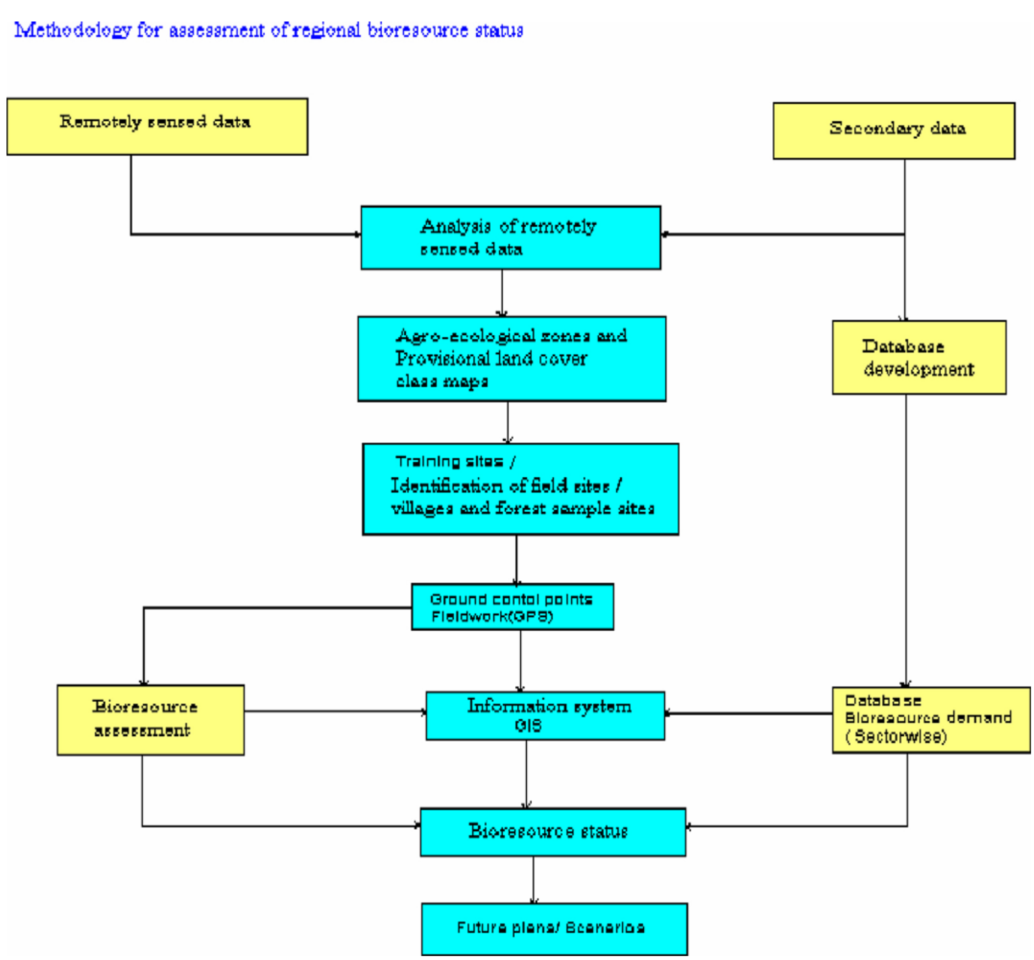


Fig. 1.3. Methodology for assessment of regional bioresource status.

is intended to indicate that responses in the form of energy efficient devices and planting of polyculture plant species are necessary.

3.3.2. The wind resource module

This module determines the wind potential in a region for (a) water pumping purposes and (b) wind farms—for electricity generation. This assessment is based on wind data—monthly, seasonal and yearly change of wind speeds (based on daily and hourly values) and wind speed at various elevations. Based on available wind resources and extent of land (feasible sites) to set up wind farms, wind resource module projects the wind energy that could be harnessed for electricity generation. Techno-economic analysis decides the viability of wind energy systems in a region [31].

3.3.3. Solar energy module

The solar energy module is similar to wind energy module. Based on solar radiation and meteorological data, feasible solar energy sites could be determined through this module [32]. Land use details provide the extent of land available for harnessing solar energy through either solar thermal devices or photovoltaic devices. Techno-economic analysis is intended to decide technical, economic, ecological and social aspects, and acceptability of devices in a region.

3.3.4. Hydroelectric energy operation module

The main functions of this module involve the answering of basically the following questions: (1) How much energy can be generated using flowing water of a river/stream and what is the reliability of such decisions? (2) How to operate a reservoir on a daily basis, taking seasonal constraints in order to achieve this goal? (3) How to maximise the net energy available in the region, while reducing submergence and construction costs?

The planning operation module will answer all these questions based on predetermined hydrological flow (database module, environmental and socio-economic module), GIS module, technical data, economic data and a certain user selected reliability level. It also generates adaptive operation policies based on this reliability level [33,34]. Fig. 1.4 shows the components of the planning operation module. The sequential operation of this module is as follows:

(1) Start at beginning of the monsoon season.
(2) User determines reliability level.
(3) Manager module querys database record for historical flows of the system, and watershed module to predict inflows in the system.
(4) Manager module starts the statistical module to generate mass curves and statistical parameters.
(5) Manager module starts the environmental and socio-economic module for determining demands and constraints on the system (minimum reservoir level, water demands, downstream flows, etc.), and starts forecasting module to forecast rainfall and/or demands at the defined lead time.
(6) The manager module starts unsteady flow routing module to give initial guess on routings and flow constraints.
(7) GIS module, with contour mapping (elevation) details, provides the submergence area for various dam heights, land use particulars and bioresources availability in the region.
(8) Technical data module provides technical details of electrical machineries, dam, turbine, generator efficiencies, and dependability norm for storage capacity.
(9) Energy demand data module provides energy demand (electricity and fuel wood in the region), which helps in designing operation policies during the lean season.
(10) Economic data module provides civil construction costs for various types and heights of the dam, cost of electrical machineries of various capacity, environmental costs, rehabilitation costs, land use details, and land submergence costs, construction time of each design, inflation rate, operation and maintenance costs, and depreciation costs.
(11) Adaptive optimum control module decides the quantity of water drawn from the reservoir, taking into account seasonal constraints, volume of water stored for particular height of dam, seepage loss, evaporation loss, dead storage capacity of dam, and rate of sedimentation, so as to ensure there is no wastage of water. This also decides on storage capacity of a reservoir during non-monsoon season. Net energy available in the region is also presented in this module.

    Step (6) is recalled by manager module to update routing and flow constraints. This is repeated till convergence is obtained. Manager module starts GIS module to present changed submergence area for changed water drawn policies (that is for changed height of dam), reservoir levels, thus repeating the process for various reliability levels and dam heights:
(12) Results are tabulated using spreadsheet software.
(13) Operating rules are presented, and return to main module.

3.3.5. Micro/mini/small hydropower plants module

The potential assessment of feasible sites for seasonal hydropower plants in a region is carried out in this module [34]. Quantity of water, terrain, technical and economic viability of plants decide the implementation of the project.

3.4. The evaluation module

This consists of cost benefit analysis and environment programs—used to compute the overall economic and environmental consequences of alternative energy futures. The cost benefit option allows the incorporation of technology and project costs, inflation and discount rates into a comparison of policy scenarios, as well as, costs of environmental externalities.

3.5. Computation models

The energy planning endeavour for a particular region involves the finding of a set of sources and conversion devices, so as to meet the energy requirements/demand of all the tasks in

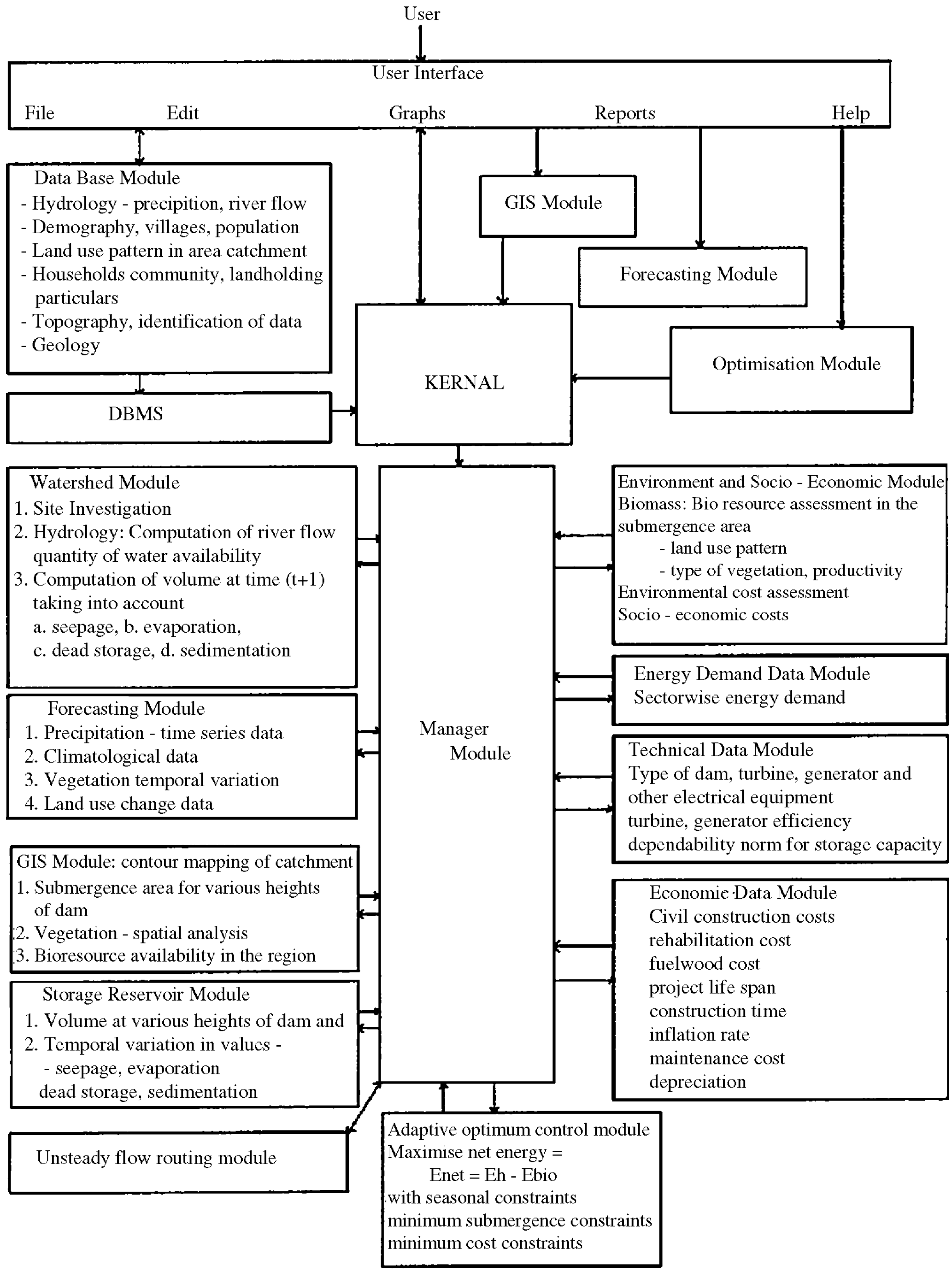


Fig. 1.4. Design of hydroelectric station with optimal storage option—detailed operation module.

an optimal manner. This optimality depends on the objective to minimise the total annual cost of energy. Factors such as availability of resources in the region and task energy requirements impose constraints on the regional energy planning exercise. Thus, the regional energy planning turns out to be a constrained optimisation problem. The basic components in the design are

(i) *Regional energy system*: Resources form inputs and consumptions by different tasks via varied technologies of conversion form outputs in the regional energy system. The energy sources are both renewable and non-renewable. Renewable resources presently in wide use in Uttara Kannada district are firewood, agro residues and animal wastes. Out of these resources, firewood is fast dwindling because of its uncontrolled and inefficient usage and increasing demand due to increase in population, affecting adversely the quality of life and environment. This is evident from barren hilltops in the densely populated coastal taluks of Karwar, Kumta, Honnavar, Ankola and Bhatkal. There is thus, an urgent need to tap new and technically feasible resources, such as, solar, wind,

potential energy of water and biogas, in a decentralised way [23]. The renewable energy resources readily available in the region are

(1) Bioresources: firewood, agricultural and horticultural residues, animal wastes—either used directly or converted into biogas [28,30].
(2) Potential energy of water: used to drive mechanical devices, and converted to electricity [35,36].
(3) Wind energy: converted to rotary mechanical energy using turbines, and converted to electricity [37–39].
(4) Solar radiation: can be used directly through thermal device-flat plate collectors or concentration, and converted to electricity using PV (photovoltaic) or thermal devices [40–43].

Resources such as tidal wave energies are still in experimental stage and are not estimated/included in the regional energy plan.

(ii) *Tasks*: The tasks can be categorised based on their thermodynamic characteristics, such as, type and quality of energy needs [23,24]. These are

(1) Low grade thermal energy (less than 100 °C): needs, such as, domestic water heating, space heating, grain drying, and process heat for small-scale industries.
(2) Medium grade thermal energy (100–300 °C):
   - cooking in households,
   - village industries, such as, jaggery making, areca boiling, parboiling, etc., and
   - small-scale industries, such as, cashew processing, brick kilns, tile industries, etc.
(3) Lighting: domestic, community, industrial, etc.
(4) Mechanical works (rotating mechanical shaft power):
   - pumping water for domestic purposes, irrigation, etc., and
   - small-scale industries like rice mills, etc.
(5) Motive power: agricultural operation and transportation.

(iii) *Integration of sources*: System integration involves mixing of all sources via a number of devices to meet the demand of various tasks. An optimised regional energy system involves proper mix of energy systems, which involves proper mix of energy sources that supply energy required for various tasks through appropriate devices based on the second law of thermodynamics. The sources may be primary and local in nature (firewood, solar, wind, etc.) or intermediate, which are produced within a region, such as, electricity from solar, wind and bioresources, producer gas from wood, biogas from organic wastes (such as animal dung, green leaves, etc.) or non-local resources transmitted/transported from outside the region, such as, grid electricity, kerosene, diesel, petrol and LPG.

There are various approaches in integration, such as

(a) *Combining*: In combining sources approach, two or more energy sources act in conjunction to perform a single task. For example, biogas and diesel are both used to run an engine which could be coupled to centrifugal pump to pump water, or to a generator to generate electricity for lighting, pumping, industrial applications, etc.
(b) *Cascading*: Principle of cascading involves usage of heat or waste energy (low grade energy) that is produced while performing a task. This low grade energy could be used for low grade thermal energy tasks. For example, waste heat from an engine may be used to carry out a heating task.
(c) *Time sharing*: Devices make use of same resources for different tasks at different intervals of time.

In an integrated energy system, integration occurs at three levels. Firstly, several energy sources are integrated into a single energy system. Secondly, traditional components are integrated into introduced technologies. Thirdly, energy system is integrated into the fabric of the local society. Such integrated systems change continuously as they are adjusted to new situations of energy availability and utilisation. Hence, the regional energy systems must be dynamic and interactive to be effective. But, Uttara Kannada region is basically rural and economy is sluggish, hence the first two levels of integration suggested are more valid. Integration of various resources and devices to perform various tasks in a region is listed in Fig. 2.

4. Design approach

The design of the regional energy system involves finding the quantities of various energy resources required per year and the capacities of devices that minimise the total cost per year.

Let 'M' be the number of resources used/considered to perform 'N' tasks and 'D' be the number of devices.

Let

X_1 = quantity of fuel wood/year
X_2 = quantity of biogas/year
X_3 = quantity of wind
X_4 = quantity of solar energy (thermal + PV module)
X_5 = quantity of hydroelectric energy (micro/mini/small and dam option at Unchalli of Aghnashini and Magod of Bedthi river)
X_6 = electricity from Karnataka Electricity Board
X_7 = quantity of kerosene distributed in the district per year
X_8 = quantity of petroleum products

Each of the resources listed above may be used for more than one task, through various devices.

Thus, X_{ijk} is the portion of X_i required for jth task through kth devices.

Therefore,

$$X_i = \sum_{j=1}^{N} X_{ijk} \tag{1}$$

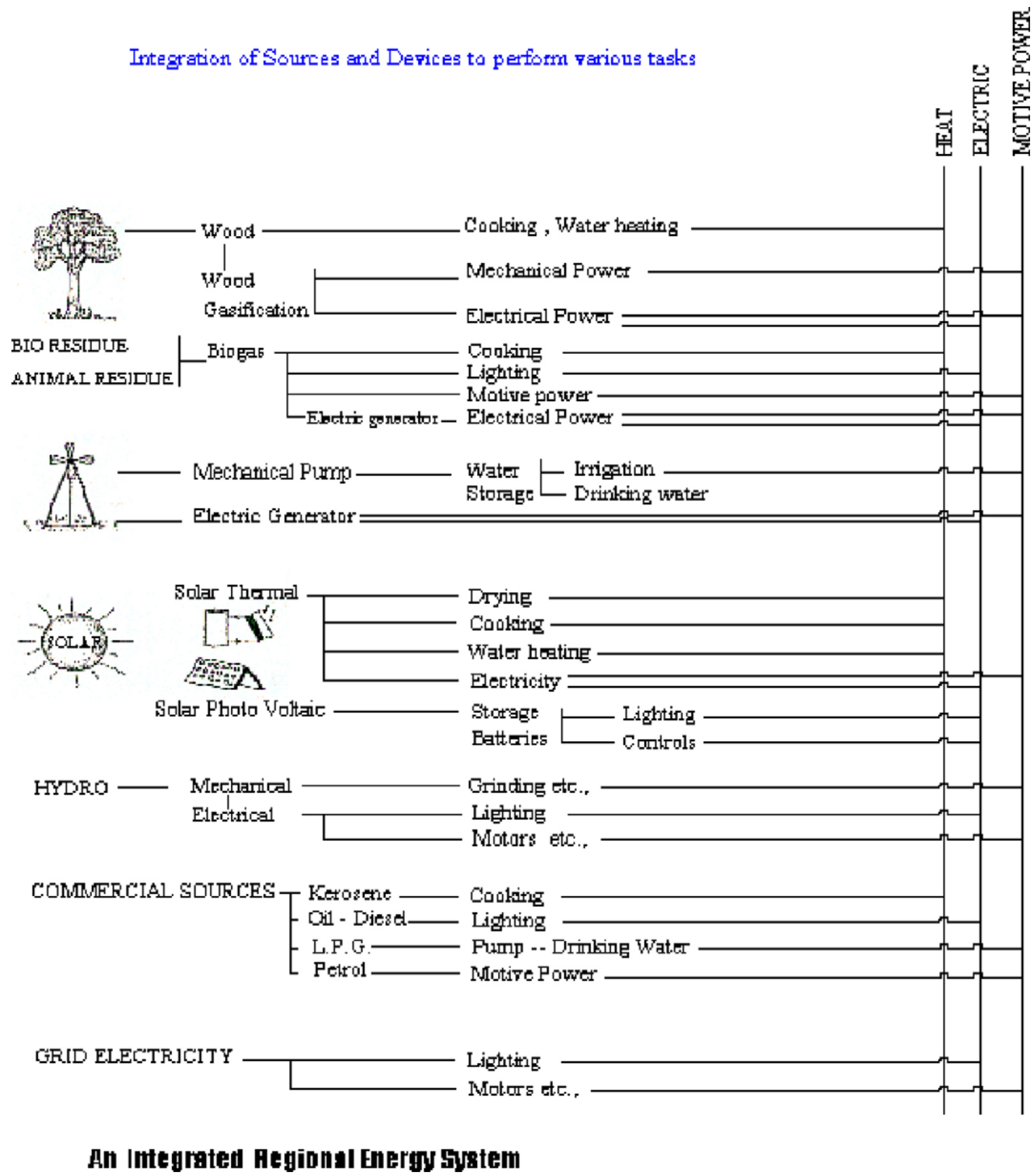


Fig. 2. Integration of sources and devices to perform various tasks.

Energy equivalents: The energy equivalents of the various resources computed are denoted by "R_i":

$$\text{For e.g.,} \quad E_i = R_i X_i \tag{2}$$

$$\text{and} \quad E_{ijk} = R_i X_{ijk} \tag{3}$$

$i = 1$, R_1 is the energy equivalent of fuel wood per tonne (5112.8 kWh/t),
$i = 2$, R_2 is the energy equivalent of biogas in kWh per cubic meter (5.55 kWh/m^3),
$i = 3$, R_3 is the annual rotating mechanical energy output of wind turbines in kWh/m^2 of swept area,
$i = 4$, R_4 is the annual thermal energy collected by solar thermal collector in kWh/m^2,
$i = 5$, R_5 is the potential energy stored in water in kWh/m^3,
$i = 6$, R_6 is the energy equivalent of electricity supplied through grid (=1),
$i = 7$, R_7 is the energy equivalent of kerosene (8690.717 kWh/kl),
$i = 8$, R_8 is the energy equivalent of petroleum products (9585.35 kWh/kl).

The regional energy planning design problem involves means to meet the increasing demand for energy of the region from various resources, with the objective of minimisation of total cost and the constraints associated with various resources and loads to be supplied. Thus, this involves design of total annual cost function and the constraint equations.

4.1. Problem formulation

A source may be meeting, either partially or fully, the energy requirements of more than one task at a given time.

The cost C_{ijk} per year thus would be

$$C_{ijk} = (A_{ac})_{ijk} E_{ijk} \quad (4)$$

where $(A_{ac})_{ijk}$ is the annualised cost of ith resources for jth task.

$$(A_{ac})_{ijk} = \left[\frac{r(1+r)^{n_{ijk}}}{(1+r)^{n_{ijk}} - 1} + OC_{ijk} \right] \quad (5)$$

where r = annual interest; n = time period and; OC = operation and maintenance cost.

For M resources and N tasks, the total cost/year is

$$C = \sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{k=1}^{D} C_{ijk} = \sum_{i=1}^{M}\sum_{k=1}^{N}\sum_{j=1}^{D} (A_{ac})_{ijk} \quad (6)$$

but $E_{ij} = R_i X_{ij}$.

$$C = \sum_{i=1}^{M} R_i \sum_{j=1}^{N}\sum_{k=1}^{D} (A_{ac})_{ijk} X_{ijk} \quad (7)$$

The design approach minimises 'C' total cost subject to a set of constraints.

4.2. Constraints

(1) *Task satisfaction*: It is the first constraint in the regional energy system. The total energy supplied by the sources should be equal to the energy requirements of the tasks.

If U_j is the (useful) energy requirement of task j (based on field data collected from various surveys) and X_{ijk} the quantity of energy obtained from source 'i' via device 'k' for task 'j', then

$$\sum_{i}^{M}\sum_{j}^{N}\sum_{k}^{D} U_{ijk} = \sum_{i=1}^{M} R_i \eta_{ijk} X_{ijk} \geq U_j$$
$$j = 1, \ldots, N, k = 1, \ldots, D \quad (8)$$

X_{ijk} = amount of end use demand supplied for jth task (through kth device by an ith source); η_{ijk} = efficiency; R_i = energy equivalent of ith source.

(2) *Availability of local resources*: There is an upper limit on the availability of local resources. Therefore, the total amount of a particular resource consumed for various tasks should be less than or equal to the corresponding maximum value. For ith resource if E_i max is the maximum energy available, then

$$E_i \max \geq R_i \sum_{j=1}^{N}\sum_{k=1}^{D} X_{ijk} \quad j = 1 \ldots\ldots N, k = 1, \ldots, D \quad (9)$$

Since $E_i \max = R_i X_i \max$, the above equation can be written as

$$X_i \max \geq R_i \sum_{j=1}^{N}\sum_{k=1}^{D} X_{ijk} \quad i = 1, \ldots, M', \quad j = 1, \ldots, N \text{ and } k = 1, \ldots, D \quad (10)$$

where M' ($<M$) be the number of local energy resources and the subset of the set M of all energy resources (that is, $i = 1, \ldots, M'$ and $M' \leq M$). This constraint also takes into account the limited availabilities of some of the local resources.

If M'' is the subset of these resources having limited availabilities, R_i is the maximum energy available from source i ($i \varepsilon M''$).

(3) *Non-negativity*: All X_{ijk} values must be non-negative:

$$X_{ijk} \geq 0 \quad (11)$$

for $i = 1, 2, \ldots, M$; $j = 1, 2, \ldots, N$; $k = 1, 2, \ldots, D$.

(4) *Power requirements*: The fourth constraint is that some tasks have definite power requirement. The constraint imposed by the rate of energy use (power) should also be considered in regional energy planning. If P_{ijk} is the power required for handling the jth task supplied by ith resource via kth device, then the maximum rate of energy use expected of ith resource P_i is

$$P_i = \frac{1}{d_i} \sum_{j=1}^{N}\sum_{k=1}^{D} P_{ijk} \quad (12)$$

where d_i is the diversity factor for the tasks 'j' supplied by the ith resource, and it is ≥ 1:

$$d_i = \frac{\text{sum of individual maximum demand}}{\text{net maximum demand}} \quad (13)$$

If P'_j is the maximum power required for performing jth task, then $X_{ijk} = 0$, if $P_{ijk} < P'_j$. This condition can be used to eliminate the source–device combinations, which cannot yield adequate power for the task. In case, there is a possibility of combining sources in devices, then the condition would be

$$X_{ijk} = 0, \quad \text{if} \sum_{j=1}^{N}\sum_{k=1}^{D} P_{ijk} < P_j \quad (14)$$

It is also essential that the sum of the power outputs of the ith energy source through all the paths 'ijk' should not exceed maximum power P_i, which the source can develop:

$$P_i \geq \sum_{j=1}^{N}\sum_{k=1}^{D} P_{ijk} \quad (i = 1, 2, \ldots, M) \quad (15)$$

If the total energy derived per year from the ith resource for all tasks is E_i and if K_i is the effective load factor experienced, then the available power rating is

$$Pa_i = \frac{E_i}{8760 K_i} \quad i = 1, 2, \ldots, M \quad (16)$$

The power constraint is $P_i \leq Pa_i$ ($i = 1, 2, \ldots, M$).

But, P_{ijk} is the contribution of power output for jth task from ith resource through kth device:

$$P_{ijk} = \frac{E_{ijk}}{8760 K_{ijk}} \quad (17)$$

But,

$$E_i \max = \sum_{j=1}^{N}\sum_{k=1}^{D} E_{ijk} = R_i \sum_{j=1}^{N}\sum_{k=1}^{D} X_{ijk}$$

Therefore,

$$P_{ijk} = \frac{E_{ijk}}{8760K_{ijk}} = \frac{R_i X_{ijk}}{8760K_{ijk}} \tag{18}$$

The power constraint $P_i \leq Pa_i$ becomes

$$\frac{1}{k_i}\sum_{j=1}^{N}\sum_{k=1}^{D} X_{ijk} - \frac{1}{d_i}\sum_{j=1}^{N}\sum_{k=1}^{D} \frac{X_{ijk}}{K_{ijk}} \geq 0, \quad i = 1, 2, \ldots, M \tag{19}$$

While, K_{ijk} is the load factor, based on its definition and physical significance, it can be written as

$$K_{ijk} = \frac{E_{ijk}}{8760P_{ijk}} = \frac{U_{ijk}}{8760P_{ijk}\eta_{ijk}} \tag{20}$$

Thus, the regional energy planning exercise becomes an optimisation problem, which is stated as follows:

- Minimisation of the annual cost function C

$$C = \sum_{i=1}^{M} R_i \sum_{j=1}^{N}\sum_{k=1}^{D} (A_{\mathrm{ac}})_{ijk} X_{ijk} \tag{21}$$

- Subject to the constraints

(1) $$\sum_{i=1}^{M} R_i \eta_{ijk} X_{ijk} \geq U_j \quad j = 1, \ldots, N, k = 1, \ldots, D \tag{22}$$

(2) $$X_i \max \geq R_i \sum_{j=1}^{N}\sum_{k=1}^{D} X_{ijk} \quad i = 1, \ldots, M', \text{(where } M' < M), j = 1, \ldots, N, k = 1, \ldots, D \tag{23}$$

(3) $$\frac{1}{k_i}\sum_{j=1}^{N}\sum_{k=1}^{D} X_{ijk} - \frac{1}{d_i}\sum_{j=1}^{N}\sum_{k=1}^{D} \frac{X_{ijk}}{K_{ijk}} \geq 0, \quad i = 1, 2, \ldots, M \tag{24}$$

(4) $$X_{ijk} \geq 0 \quad \text{for } i = 1, 2, \ldots, M, \; j = 1, 2, \ldots, N, k = 1, 2, \ldots, D \tag{25}$$

4.3. Design implementation

The formulation presented above for regional energy planning is tried for the data collected from extensive field surveys in Uttara Kannada district. Eight resources and six tasks are considered for demonstrating the usefulness of the design approach presented in the previous section. In arriving at the energy requirement for different tasks, aggregation has been done. For example, all the loads requiring rotating shaft power (such as water pumping, some agricultural operations, motor load in small-scale industries) are aggregated into one task (rotating mechanical power). The resources and tasks considered in this design are as follows:

Resources:
$i = 1$, fire wood, agricultural residues;
=2, biogas;
=3, wind energy;
=4, solar energy;
=5, hydropower resources (micro/mini/small, etc.);
=6, grid electricity;
=7, kerosene;
=8, petroleum products (petrol, diesel, etc.).
Tasks:
$j = 1$, low temperature heating (water heating, drying, space heating, etc.);
=2, medium temperature heating (primarily cooking, etc.);
=3, high temperature heating (furnace, industrial applications, etc.);
=4, lighting (domestic, industrial, street lighting, etc.);
=5, rotating mechanical power (irrigation, industrial applications, etc.);
=6, motive power (transportation, etc.).

4.4. Data used in the design: tasks or end-users

Identification of various tasks and their energy requirements, and also peak power requirements (if any) constitute the first step in regional energy planning.

The regional energy tasks can be categorised as (i) domestic, (ii) agricultural, (iii) industrial, (iv) transport, and (v) commercial and service sectors. They can also be classified according to the quality or grade of energy requirements (thermodynamic characteristics). For example, cooking is a domestic task requiring medium temperature heat, and crop drying an agricultural task requiring low temperature heat.

(i) *Domestic*: Cooking and water heating (for bathing) are the most important domestic activities in Uttara Kannada. Survey carried out in the domestic sector shows that the domestic sector mainly depends on fuel wood. This region is rich in bioresources; the noncommercial sources of energy (fuel wood, agricultural residues and animal waste) consumption constitutes about 97.15% of the district's total consumption. Out of this, firewood's share is about 59.02%, mainly in the domestic sector. Firewood is collected from nearby forests or from *betta* lands twice a year (discussed earlier in detail) in the hilly areas of the district, while in coastal taluks, due to scarcity (depletion of forest resources), villagers make frequent trips to nearby sources to gather fuel wood, mostly in the form of twigs and branches. Apart from these, in the coastal area, the forest department has made arrangement to supply fuel wood at subsidised price, based on ration card, at the rate of 15 kg/(person month) [28–30].

Detailed household survey carried out in Kumta taluk (seasonwise) shows that fuel wood consumption ranges from 2.07 ± 0.38 (summer), 2.13 ± 0.37 (winter) to 2.31 ± 0.41 kg/(person day) (monsoon) for cooking. While for water heating, it ranges from 1.29 ± 0.29 (summer), 1.39 ± 0.36 (winter) to 1.47 ± 0.36 kg/(person day)

(monsoon). This shows very minimal seasonal variation in domestic sector's fuel wood consumption.

In the coastal area, due to fuel wood scarcity, households also use kerosene for cooking. It ranges from 0.34 ± 0.79 (coastal) to 0.05 ± 0.19 l/(person month) (hilly area). Due to availability of bioresources in large quantity, households in the domestic sector have switched over to biogas in Sirsi and Siddapur taluks. Biogas consumption ranges from 0.23 (coast) to 0.49 m^3/(person - day) (hilly area).

LPG (liquified petroleum gas) consumption ranges from 0.02 (coastal zone) to 0.01 kg/(person month) (hilly zone).

Lighting needs: This also constitutes one of the essential needs in the domestic sector. Most of the villages in the district are electrified except very remote locations, such as, Yana, Sandolli, Medine, Kalave (Kumta taluk), Mogadde and Uddal (Sirsi). In electrified villages, all households are electrified. Under Bhagyajyothi scheme, the poor and socially backward categories have been provided one bulb in each household (free installation). To meet the lighting requirement in other parts of the house in these households, and due to erratic power supply by the centralised system (KEB), they still use kerosene wick lamps for illumination. These lamps, however, have low efficiencies and poor illumination. Kerosene consumption for lighting on average ranges from 0.82 (summer) to 0.87 l/(person - month) (monsoon). Electricity consumption (at present, mainly lighting) is about 2.22 kWh/(person month) in this region [28].

(ii) *Agriculture*: Uttara Kannada district's economy mainly depends on agriculture and horticulture. Land preparation, irrigation, harvesting, threshing and transportation are the main tasks dependent on mechanical form of energy apart from manure input, seed, etc. At present, rainfed paddy is the major crop in agriculture and, hence, less dependent on irrigation. There is scope to grow second crop in this region, which involves irrigation. This can be met either from animate or inanimate sources of energy. The water requirement and associated average daily energy requirements depend on the area irrigated, type of crop, sources of water, total period of irrigation and irrigation efficiency. Uttara Kannada's agricultural sector is active only during monsoon. During lean season, fodder crop is grown in some places (such as Banavasi), which enriches the soil by increasing its nitrogen content [44]. Apart from this, horticulture work, such as, land preparation and mulch manure application is done during the season when agriculture is not carried out. Most of the horticultural land owners are also agricultural land holders. However, there is scope for second crop in the coastal and plain regions (such as Mundgod). Cooking, water heating and lighting energy requirements are to be met daily, while the energy requirements of agriculture (such as, land preparation, irrigation, harvesting, etc.) depend on the cropping pattern and season.

(iii) *Industries*: Industries in Uttara Kannada can be grouped as large- and medium-scale, small-scale and village industries, such as, brick kilns, jaggery making units, etc. Large and medium-scale industries are located mainly in Karwar and Haliyal, while small-scale industries, such as, agro processing units, rice mills, etc., are distributed all over the district. Operations such as jaggery making, etc., are seen only during certain seasons [45,46]. Most of the small-scale and village industries depend on fuel wood and agriculture residues to meet their heating needs, since electricity is mainly used for lighting activity. However, large and medium-scale industries such as caustic soda and chemicals (liquid chlorine, hydrochloric acid, etc.) manufacturing sector are dependent mainly on electricity. Alternative sources and technologies to meet the energy needs of the industrial sector are available now. Quantitative analyses of resource and techno-economic analyses of technologies done earlier, show that viable alternatives are available to meet the local energy requirement [28–30]. The industrial energy requirement is estimated based on the sample survey conducted in Kumta and Sirsi taluks [45].

4.5. Resources data

With the tasks and corresponding energy requirements identified, the next step in the regional energy planning exercise is to look at the sources, including traditional ones, to perform these tasks.

Firewood is the main source of energy for cooking in Uttara Kannada district. Water heating task is carried out with agriculture residues and firewood. Survey of 1304 households in Kumta taluk reveals that most of them still use traditional stoves, the efficiency of which is in the range of 10–15%. Kerosene and LPG (very small percentage: 0.0025) are among the noncommercial (non-local) resources used in Uttara Kannada. Kerosene is used largely for lighting. Grid electricity is used for lighting and in few households for energising pumpsets to irrigate the plantations during lean season [28,29].

Agriculture in Uttara Kannada depends mainly on animate sources of energy, such as, draught animal power, human power, etc. Organic farming is practiced in most sampled households.

Analyses of bioresources [27–29] show that biogas can meet cooking and lighting needs of at least 30% population (in Uttara Kannada district). The biogas potential (based on available animal residue) ranges from 11.42 to 19.45% (in coastal area), and 19.92 to 54.69% (in hilly area).

Producer gas engine can provide necessary motive power required for agricultural pumpsets, tractors and tillers. Wood required for producing producer gas through gasifiers can be raised from energy plantations on degraded land (is necessary). Availability of local resources is limited due to various factors. These are

(1) Size and number of devices required to harness a source, like the number of wind mills used and the energy they can

capture depend on (a) wind regime and the total swept area, and (b) solar radiation size of PV module/collector area (thermal devices).
(2) In the case of animate sources, the available energy depends on their use hours/day and the capacity of sources.
(3) The amount of raw material available for production (e.g., animal wastes for biogas, wood for producer gas, etc.)
(4) In the case of hydropower resources, it depends mainly on precipitation-quantity of water and head of water drop at site.

4.6. Assumptions

4.6.1. Scenario I—base case scenario

The base case demand projections assume that energy consumption is basically determined by the growth rate of the population and level of development in the region. The dependency of energy demand was modelled, quite simply as a direct relationship, between demand and population. For this purpose, to project population growth rate, population data provided by directorate of census operation for last 30 years (1961–2001) has been used. The energy growth rate used in the base case and transformation case, was based on the information provided by The Planning Unit, District Planning Division, Uttara Kannada Zilla Parishad at Karwar. The energy growth estimate used in Scenario I (base case) and Scenario II is based on the assumption that policies of 1990s and 2000 will be maintained.

In the base case scenario, changes in demand are assumed to follow changes in key driving parameters. For the domestic sector, future demand was assumed to be proportional to population growth, that is, in the range of 2.07–2.34% per year. Agricultural and commercial changes in demand are linked to growth in overall economy. For the industrial sector, demand in each subsector/group was assumed to increase in proportion to growth in industrial production. Average industrial and overall energy growth levels were assumed to be around 2.8 and 2.45% per year between 2000 and 2015.

4.6.2. Scenario II—high-energy intensity

In Scenario II, for industrial sector, 20% increase in the intensity of useful energy consumption for thermal end use (such as, direct heat, steam generation, etc.) between 2000 and 2005 and 30% increase between 2005 and 2015 is assumed. For the end uses that require electricity (such as, motor, lighting, etc.) a 10% increase from 2000 and 2005 is assumed, with a further 10% increase over base year levels by 2015. The basis of the growth in intensity assumed for the thermal end uses is that Uttara Kannada's regional economy is basically rural and sluggish that characterises this scenario result in inadequate utilisation of industrial capacity.

4.6.3. Scenario III—transformation case scenario

The transformation case scenario implies substantial changes in attitude about energy consumption within the region. In this aspect, this scenario is granted less apparent probability of occurring than Scenario II. This scenario assumes policies of savings and conservation in almost all sectors, as well as, improvement in the efficiencies of energy consumption and energy transformation equipment. In the industrial sector, the amount of useful energy consumed per unit industrial value added is assumed to decline by 2% between 2000 and 2005, with further 2% decrease by 2015. The result of this assumption is a reduction in the energy intensity for the majority of end uses, and a major proportion of the overall reduction are in end uses that require heat (such as rural industries-cashew processing, etc.). In the domestic sector, 3.5% growth in the electricity consumption per household for end uses, such as, illumination, domestic appliances, etc., is assumed for the period between 2000 and 2015. This increase is based on the growth on income and therefore on the growth in overall economic consumption per capita. For the cooking end use, it is assumed that at least 50% of households using fuel wood, LPG and electricity as fuel by 2010 will have energy efficient devices than those in place of 2000. These efficient devices are assumed to have efficiencies of 35% (wood stoves), 78% (electric) compared with 2000 efficiencies of 7–8% (wood devices) and 60% (electric), respectively. Also, it is assumed that at least 15% of total population would switch over to biogas devices for cooking purposes. (Calculations show [29,30] that biogas from dung resource is sufficient to meet demand of 30% of the population.)

4.6.4. Scenario IV—state growth rate

The intent here is to develop a scenario for Uttara Kannada district based on state energy consumption norms. The projection of industrial and total energy consumption norms (industrial, agriculture, etc.) was used. The average growth is significantly higher in this case than in the base case (5.74% per year for industrial and 4.0% for overall). The growth rate in coal consumption is about 2.35%, kerosene 3.26%, electricity 8.51%, LPG 19.46%, fuel wood 1.95% and agricultural residues about 3.85% (these growth rates are computed from time series data by regression analyses method). Directorate of Census operation projections were used for total population, persons per household and rural/urban fractions.

4.6.5. Scenario V; Scenario IV + efficiency improvements case

This scenario, in addition to policies of Scenario IV, assumes the efficiency gains that are quite achievable for a given technology. In the domestic sector, most households still use incandescent bulbs (about 92% of sampled households in five taluks of Uttara Kannada district). The efficiency of lighting devices is assumed to increase through the introduction of compact fluorescent lamps (CFL). These devices, which produce nearly five times the light per unit energy input compared to incandescent bulbs, and have nearly eight times the life, are assumed to provide 5% of lighting by 2005, and 10% by 2015. These CFL's have relatively higher initial costs. But taking into consideration the energy saved (due to low wattage requirement), and longer life, calculations indicate saving of about 52% over a period of time. The fuel efficient cooking and water heating devices show saving of about 27%

[28,29]. Solar water heaters in coastal taluks of Uttara Kannada district are found to be viable alternatives. For cooking devices, this scenario assumes that more efficient stoves replace traditional stoves, as in the Transformation scenario. In addition to this, 15% adoption of solar hot water devices by 2010 is assumed. The efficiency of fuel use in services and commercial sector is assumed to improve for all fuels by 10% (2005) and 20% (2015), relative to base year results.

5. Results and discussion

Sectorwise energy demand and resource potential compiled in the following section are based on the detailed investigations carried out earlier [27–30,35–37,39–42].

5.1. Energy demand

Compilation of survey data and sectorwise analyses show that noncommercial sources of energy, such as, firewood and agricultural residues are the major components in the districts energy consumption. Table 1.1 lists sectorwise energy demand based on detailed investigations carried out in various sectors of Uttara Kannada district. It shows that the domestic sector with 77.96% (8941.56 million units-mkWh) of total energy consumption, is the major energy consuming sector followed by industrial (15.93%) and agricultural (5.13%) sectors. This is illustrated in Fig. 3.1.

Tables 1.2 and 1.3 give sourcewise consumption of energy. Uttara Kannada district mainly depends on noncommercial energy sources (96.23%), such as, firewood (78.09%), dung in the form of biogas (13.12%), and animate sources (5.02%). While, commercial sources, such as, electricity (2.86%), kerosene, diesel, petrol, etc., (0.90%) and LPG (0.0001%) constitute 3.77% of total energy consumption in the district. This is illustrated pictorially in Figs. 3.2 and 3.3, respectively. Sourcewise and sectorwise consumption of energy is listed in Table 1.4. Domestic (77.67%), industrial (13.535%) and agricultural (5.024%) sectors mainly depend on noncommercial sources of energy. This aggregated information is depicted in Fig. 3.4. Energy demand of various sources in the district is listed in Table 1.5.

5.2. Resource scenario results

Monthwise availability of solar and wind potential [37–42] in coastal taluks, and electricity that could be generated by using 5% of barren land are listed in Tables 2.1 and 2.2, respectively. While, Tables 3.1 and 3.2 give hydropower and bioenergy availability in the region, respectively.

Results of solar resource module are listed in Table 2.1. It lists monthwise amount of solar energy that could be harnessed through solar conversion devices, by utilising 10% of wasteland presently available in the coastal taluks of Uttara Kannada district. The electrical energy that can be harnessed is of the order of 191.44 million kWh, which constitutes about 65.1% of the present electricity demand from various sectors of Uttara Kannada district. These analyses also show that about 72% of solar energy is available during October to May period.

Table 2.2 lists monthwise electrical energy that could be generated by harnessing wind potential along the coastal zone of Uttara Kannada district. The availability of wind resource is quantified and characterised in detail earlier [37–39]. Due to local necessity of energy in the pre-monsoon period for industrial and irrigation purposes (for agriculture and horticulture), and the availability of wind resources during the same period, the exploitation of wind energy for mechanical and electrical energy purposes becomes feasible and desirable.

Hydropower resource module provides electrical energy potential in Bedthi and Aghnashini river basins of Uttara Kannada district. Results of this module are listed in Table 3.1.

Table 1.1
Sectorwise energy consumption (mkWh) in Uttara Kannada

Sector	Energy (in mkWh)	Share (%)
Agriculture	588.704	5.133
Commercial	11.168	0.097
Domestic	8941.560	77.959
Transport	100.570	0.877
Industry	1827.598	15.934
	11469.600	100.000

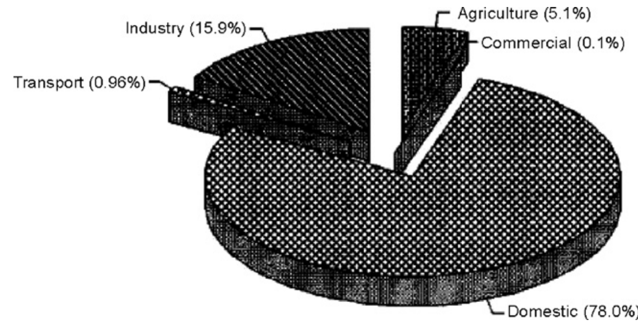


Fig. 3.1. Sectorwise energy consumption—Uttara Kannada District.

Table 1.2
Sourcewise composition of energy (mkWh) in Uttara Kannada

Source	Energy (in mkWh)	Share (%)
Noncommercial	11037.526	96.233
Commercial	432.074	3.767
	11469.600	

Table 1.3
Sourcewise and typewise composition of energy (mkWh) in Uttara Kannada

Source	Type	Energy (in mkWh)	Share (%)
Noncommercial	Firewood	8956.703	78.091
	Dung (biogas)	1504.533	13.118
	Animate En.	576.290	5.024
Commercial	Electricity	328.321	2.863
	Oil	103.750	0.904
	LPG	0.003	0.000
		11469.600	100.000

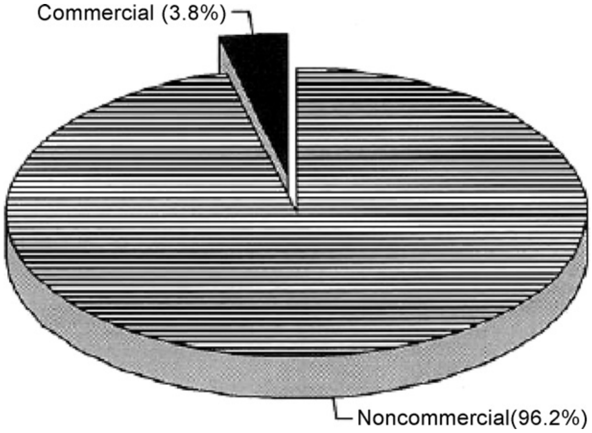


Fig. 3.2. Energy consumption sourcewise—Uttara Kannada District.

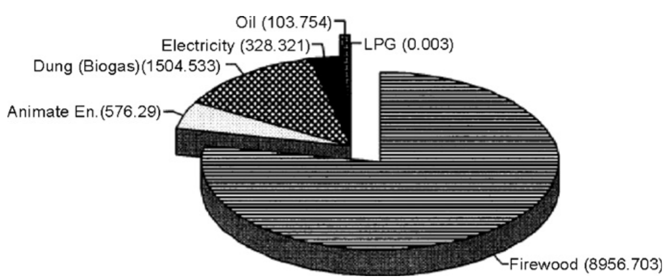


Fig. 3.3. Sourcewise consumption of energy.

It is seen that about 1787.61 million units (mkWh) of electrical energy in Aghnashini and 1079.15 million units (mkWh) in Bedthi river basin could be harnessed. Monthwise electrical energy that could be harnessed from streams and major sites at Unchalli (of Aghnashini) and Magod (of Bedthi) are shown in Fig. 4.1, while Fig. 4.2 depicts separately the total hydroenergy available in the respective river basins. The table also depicts that hydropower resource is available mainly during June to October period. Fig. 4.3 illustrates the energy available from an area of 95.8 km^2 by bioresources and hydropower resources through integrated planning approach. Hydroelectric systems for harnessing hydroenergy at Magod and Unchalli sites are designed within social and ecological constraints.

The results of biomass module provide talukwise and categorywise biomass availability and demand balances. The biomass availability is computed based on different types of

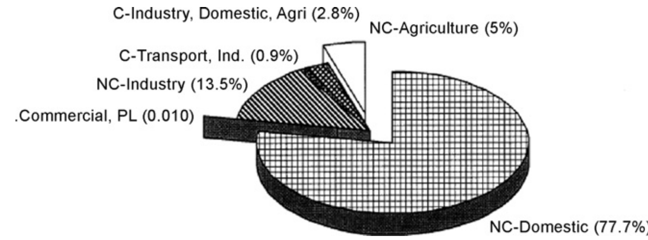


Fig. 3.4. Sourcewise, sectorwise (C: commercial, NC: noncommercial).

forest patches in the district and respective biomass productivities. Biomass module provides supply scenario for lower and upper ranges of biomass productivity. Similarly, biomass module provides bioresource demand taking into account demand range. Tables 3.2 and 3.3 list talukwise biomass availability and demand for higher and lower ranges of productivity. The same is illustrated in Figs. 5.1 and 5.2, respectively. Out of 11 taluks of Uttara Kannada district, coastal taluks Bhatkal, Kumta and Honnavar have bioresource scarcity (Fig. 5.1), while the remaining taluks have adequate resources to meet the region's demand. Talukwise bioresource availability from livestock population is listed in Table 3.4. It shows that if this resource is converted to biogas, it is adequate to meet the requirement of 30% of the total population. If the entire district is considered, bioresource supply appears to be diverse and sufficient in magnitude to comfortably sustain population pressure under the base case demand scenario investigated. As bioresource (fuel wood) enhancement strategies are pursued through social forestry, etc., complementary policies to promote technically feasible and cost effective improvements in the efficiency of end use equipment are needed. End use efficiency study carried out in randomly selected households in some villages show that there is scope for saving about 27.45% of fuel wood by switching over to energy efficient stoves.

5.3. Computation model results

An integrated energy system capable of utilising several resources such as wind energy, solar energy, hydroenergy and biogas for carrying out various tasks in a region is presented based on the design formulated earlier. The approach is based on minimisation of total annual cost, subject to a set of constraints on the requirements for various tasks. The efficiency values η_{ijk} used in the formulation for various pre-selected

Table 1.4
Sectorwise and sourcewise consumption of energy (mkWh) in Uttara Kannada

Sector	Source	Energy (in mkWh)	Share (%)
Domestic	Noncommercial	8908.773	77.673
Industry		1552.459	13.535
Agriculture		576.290	5.024
Commercial + PL	Commercial	11.168	0.097
Domestic		32.794	0.286
Industry		275.134	2.399
Agriculture		12.410	0.108
Transport		100.572	0.877
	Total	11469.600	100.00

PL, public lights.

Table 1.5
Energy demand in Uttara Kannada District (mkWh)

Type	Demand
Fuel wood	8908.778
Dung (biogas)	1552.459
Animate energy	576.290
Electricity	328.320
Kerosene	0.140
Diesel	69.130
Petrol	34.480
LPG	0.003
	11469.600

Table 2.1
Solar energy potential in Uttara Kannada District

Month	Global radiation (kWh/m^2)			Solar potential (mkWh)
	Karwar	Honnavar	Shirali	
January	5.67	5.47	5.35	8.35
February	6.27	6.10	5.73	8.33
March	6.30	6.24	6.04	9.41
April	6.69	6.39	6.30	9.54
May	6.48	6.23	6.21	9.56
June	5.10	4.93	4.50	7.24
July	4.02	4.17	3.50	5.92
August	4.84	4.86	4.78	7.17
September	5.10	5.27	5.18	7.33
October	5.41	5.35	5.25	7.99
November	5.13	5.03	5.03	7.34
December	5.12	4.97	4.79	7.54
Average	5.51	5.42	5.22	
S.D.	0.76	0.66	0.76	
Total potential				95.72

resource–task combinations are listed in Table 4.1. The K_{ijk} load factor computed using the relationship (Eq. (20)) is listed in Table 4.2. The effective plant load factor K_i and the diversity factor d_i assumed for resources are listed in Table 4.3. Capital cost values computed in Rs./kWh (computed in earlier [28,29]-techno-economic analyses) are listed in Table 4.4. The linear programming problem is solved using Lindo-LP package. The resulting optimal values are listed in Table 5.1. Optimum allocation of resources for various tasks is as follows:

E_{11}: 3266.780 million units-mkWh (wood energy for task 1),
E_{12}: 20795.340 million units (wood energy for task 2),
E_{13}: 1271.720 million units (wood energy for task 3),
E_{16}: 1892.580 million units (wood energy for task 6),
E_{22}: 346.230 million units (biogas for task 2),
E_{24}: 2588.360 million units (biogas for task 4),
E_{31}: 33.020 million units (wind energy for task 1),
E_{35}: 172.530 million units (wind energy for task 5),
E_{41}: 3742.940 million units (solar energy for task 1),
E_{46}: 1048.560 million units (solar energy for task 6),
E_{51}: 1481.580 million units (hydroenergy for task 1),
E_{55}: 1408.030 million units (hydroenergy for task 5),
E_{63}: 280.730 million units (grid electricity task 3),
E_{64}: 39.260 million units (grid electricity task 4),
E_{74}: 12.630 million units (kerosene for task 4),
E_{76}: 2.510 million units (kerosene for task 6),
E_{85}: 31.380 million units (diesel for task 5), and
E_{86}: 68.610 million units (diesel for task 6).

The optimal energy allocation is tabulated in Table 5.1. Total cost per year is about Rs. 11,930.28 million as against Rs. 18,711.08 million. Optimisation based on the cost minimisation objective shows that there is saving of about 19.19% in

Table 2.2
Wind energy potential in the district and anticipated electricity that could be generated by using 5% of waste land

Month	Wind potential (W/m^2)				Electricity generated (mkWh)
	Karwar	Honnavar	Shirali	Kumta	
January	6.26	6.23	9.23	6.25	0.16
February	8.27	6.37	9.53	13.79	0.21
March	15.55	6.52	9.95	21.59	0.33
April	30.38	8.06	12.9	28.26	0.47
May	54.84	12.45	16.03	31.99	0.69
June	57.18	13.93	18.88	54.79	0.89
July	106.8	13.78	18.41	66.36	1.25
August	64.63	11.09	16.78	57.77	0.83
September	12.83	3.58	5.35	9.41	0.18
October	4.51	2.68	4.53	8.15	0.12
November	2.85	3.41	8.22	6.65	0.12
December	3.59	6.06	24.11	12.99	0.26
Average	30.64	7.85	12.83	26.50	
S.D.	31.72	3.85	5.77	20.82	
Total potential					5.51

Table 3.1
Monthwise hydropower potential (mkWh) in Bedthi and Aghnashini basins

Month	Aghnashini			Bedthi		
	Streams	At Unchalli	Total	Streams	At Magod	Total
January	0.00	4.45	4.45	0.00	5.54	5.54
February	0.00	4.45	4.45	0.00	5.54	5.54
March	0.00	4.45	4.45	0.00	5.54	5.54
April	2.86	4.45	7.31	2.31	5.54	7.85
May	10.19	4.45	14.64	13.35	5.54	18.89
June	114.64	311.24	425.88	104.29	177.28	281.57
July	209.33	311.24	520.57	190.91	177.28	368.19
August	118.07	311.24	429.31	108.61	88.64	197.25
September	33.15	311.24	344.39	40.94	88.64	129.58
October	15.85	4.45	20.30	30.41	5.54	35.95
November	3.21	4.45	7.66	12.17	5.54	17.71
December	0.00	4.45	4.45	0.00	5.54	5.54
Sum	507.30	1280.56	1787.86	502.99	576.16	1079.15

Table 3.2
Talukwise bioresource demand and availability taking biomass productivity as 3.6 t/(ha year)

Taluk	Agriculture residue, total	Horticulture residue, total	Forest biomass (at 3.6), mkWh	Total biomass, mkWh	Fuelwood demand	
					At 1.1 t/(person year), mkWh	At 0.7 t/(person year), mkWh
Bhatkal	17.86	46.86	299.1	363.82	725.60	461.75
Kumta	26.02	96.45	559.0	681.46	754.44	480.10
Karwar	18.24	38.52	753.3	810.06	803.37	511.24
Honnavar	31.78	133.01	819.0	983.83	820.23	521.96
Ankola	23.12	44.32	1076.0	1143.46	513.53	326.79
Mundgod	21.73	7.41	985.0	1014.10	438.34	278.94
Haliyal	66.40	0.82	1124.1	1191.28	530.71	337.72
Siddapur	31.02	156.29	1146.2	1333.54	529.80	337.15
Sirsi	36.22	205.42	1900.0	2141.63	860.12	547.35
Yellapur	22.11	86.63	2087.8	2196.53	457.86	291.36
Supa	23.55	10.25	2956.2	2989.98	559.70	356.17
Total	318.07	825.97	13705.7	14849.70	6993.69	4450.53

energy and 36.24% cost reduction in overall energy system. Cost per unit (kWh) of energy with optimal allocation of energy is Rs. 0.31/kWh (as against Rs. 0.39/kWh without optimisation).

Optimisation is carried out with the objective of maximisation of efficiency of '*ijk*' combination for all combinations and results are listed in Table 5.2. The efficiency of wood devices for heating is taken as 10%. In this case biogas is first preferred

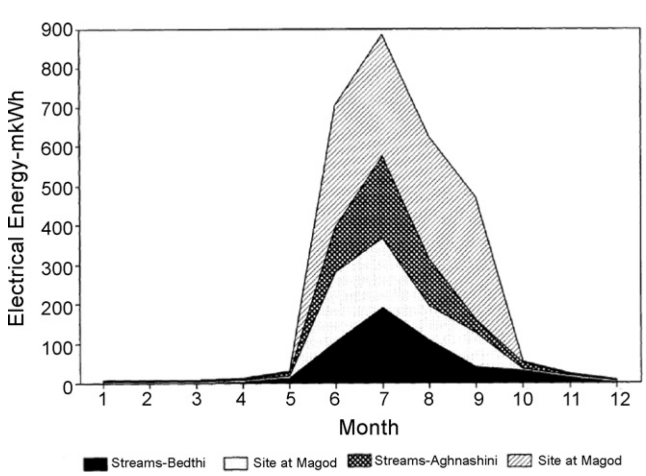


Fig. 4.1. Hydroelectric energy (streams + river) Bedthi and Aghnashini Basins.

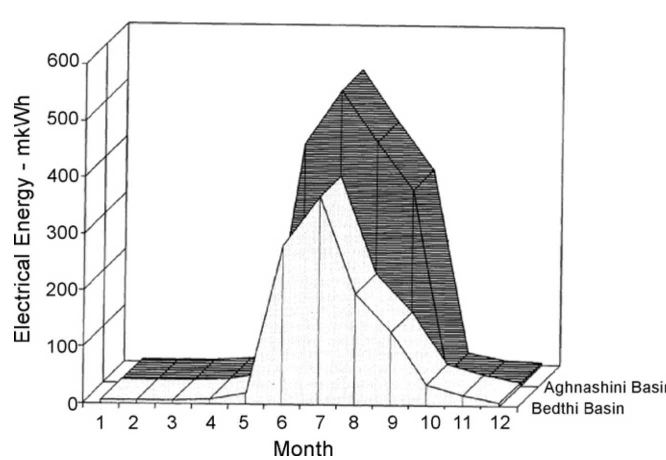


Fig. 4.2. Total energy estimated in Bedthi and Aghnashini River Basins.

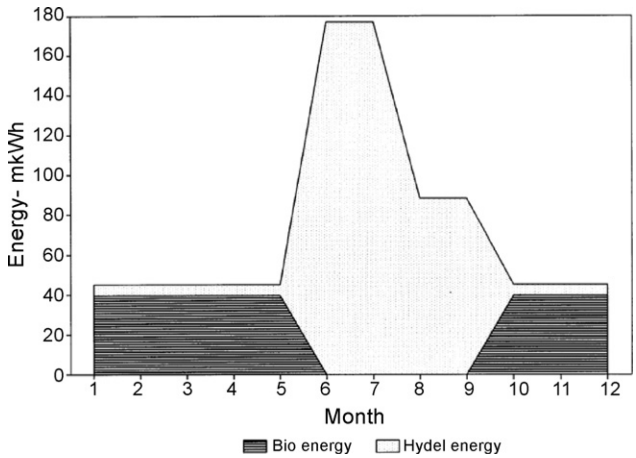


Fig. 4.3. Net energy available in Bedthi Basin—from an area of 95.8 km^2.

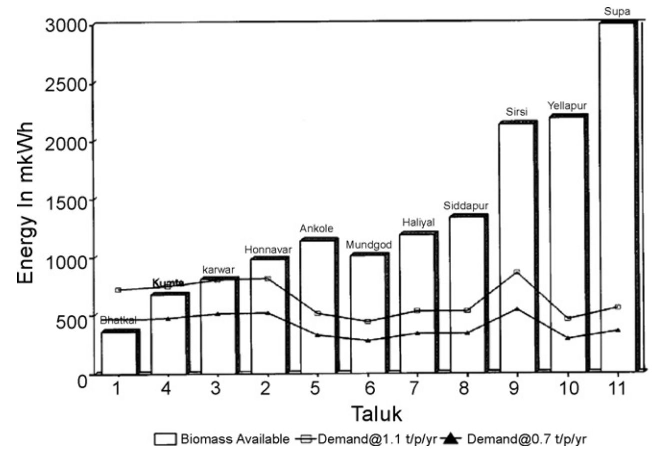


Fig. 5.1. Biomass availability and demand—talukwise, Uttara Kannada District.

for cooking (about 79%) and the balance is used for lighting. When efficiency of end use devices (for resources-1) is increased (Task 1: efficiency 30%, Task 2: efficiency of 40% and Task 3: efficiency of 30%), then firewood is preferred for cooking and biogas for lighting. The results of this simulation are listed in Table 5.3. In the case of maximisation of efficiency criteria, the energy saved is about 19.98% and total cost is about Rs. 12766.53 million. These results are listed in Table 5.4.

5.4. Demand scenario results

The energy demand during the year 2005, 2010 and 2015 is estimated based on the various scenarios discussed earlier. Results of these analyses are

Scenario I—the base case scenario: The optimal allocations of resources for various tasks, based on maximisation of efficiency criteria for the base case scenario, are listed in Table 6.1 (for the year 2005), Table 6.2 (for the year 2010) and Table 6.3 (for the year 2015). The remnant renewable resources for each task are computed and listed in these tables.

Table 6.4 presents sectorwise projections for all fuels. Overall energy use increases by 26.29% over current levels, with a nearly 54.66% increase in the use of electricity and a small increase in the annual consumption of fuel wood. Sectorwise, industrial (67.64%), transport (51.48%) and agricultural sectors (48.98%) dominate and show the strongest growth in consumption. While, consumption in domestic sector increases only slightly, as an increase in the information dissemination would result in the substitution of more efficient cook stoves and fuels, such as biogas, for cooking and water heating purposes.

Scenario II: The results of Scenario II are presented in Table 7.1 (year 2005), Table 7.2 (year 2010) and Table 7.3 (year 2015). Sectorwise projection is listed in Table 7.4. The increasing energy intensity per unit of industrial output, which is assumed in this case, leads to overall energy demand that is nearly 1852.78 million units (mkWh) higher in 2015 than in the base case, and industrial demand that is 20% higher than in the base case. The primary fuels for which demand is higher in this case are electricity, diesel and petrol. This scenario illustrates the effect of not investing in efficient devices as industrial output expands.

Table 3.3
Talukwise bioresource demand and availability taking biomass productivity as 13.5 t/(ha year)

Taluk	Agriculture residue, total	Total horticulture	Forest biomass (at 13.5), mkWh	Total biomass	Fuelwood demand	
					At 1.1 t/(person year), mkWh	At 0.7 t/(person year), mkWh
Bhatkal	17.86	46.86	532.2	596.97	725.60	461.75
Kumta	26.02	96.45	989.8	1112.23	754.44	480.10
Karwar	18.24	38.52	1333.8	1390.56	803.37	511.24
Honnavar	31.78	133.01	1463.4	1628.19	820.23	521.96
Ankola	23.12	44.32	1905.2	1972.65	513.53	326.79
Mundgod	21.73	7.41	2672.3	2701.48	438.34	278.94
Haliyal	66.40	0.82	2773.9	2841.10	530.71	337.72
Siddapur	31.02	156.29	2069.6	2256.90	529.80	337.15
Sirsi	36.22	205.42	3406.8	3648.44	860.12	547.35
Yellapur	22.11	86.63	3691.3	3800.07	457.86	291.36
Supa	23.55	10.25	5276.0	5309.75	559.70	356.17
Total	318.07	825.97	26114.3	27258.35	6993.69	4450.53

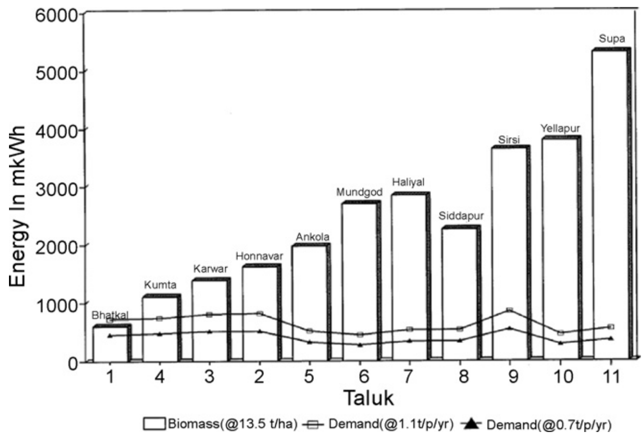


Fig. 5.2. Biomass availability and demand—talukwise, Uttara Kannada District.

Scenario III—transformation case: Tables 8.1–8.3 list the optimal allocation of resources for various tasks in the transformation scenario. Table 8.4 lists sectorwise demand. It indicates that, there is a substantial change in the sectoral shares of energy consumption by 2015, relative to the base case, and a change in the pattern of fuel use as well. The domestic and transport sectors in the transformation case use substantially less energy than in the base case, as a result of significant efficiency improvements. Industrial sector on the other hand uses 9.4% more energy than in the base case due to higher rates of energy growth and lower rate of efficiency improvement.

Scenario IV: Table 9.1 (optimal allocation for the year 2005), Table 9.2 (year 2010), Table 9.3 (year 2015) and Table 9.4 (sectorwise energy demand) show that demand in this scenario is significantly higher than any of the cases discussed earlier. This scenario is based on the energy consumption norms of the state. Overall energy consumption in 2015 is 36.32% higher than in the base case, and is 54.6% of base year demand. Unlike in the previous scenarios, fuel wood consumption does raise modestly in this scenario as a result of the large number of households.

Table 4.1
Assumed efficiency values for various resource—task combinations

i	Resource	Task					
		$j=1$	2	3	4	5	6
1	Firewood + residues	0.10	0.10	0.10	0.10	0.25	0.30
2	Biogas	0.30	0.40	0.20	0.10	0.30	0.30
3	Wind	0.10	0.10	0.30	0.10	0.40	0.30
4	Solar	0.60	0.60	0.20	0.10	0.30	0.30
5	Water	0.10	0.10	0.20	0.10	0.60	0.30
6	Grid electricity	0.10	0.15	0.20	0.10	0.40	0.30
7	Kerosene	0.25	0.15	0.15	0.05	0.25	0.10
8	Petroleum products	0.15	0.15	0.15	0.10	0.35	0.30

Table 4.2
K_{ijk} values for various resource—task combinations

i	Resource	Task					
		$j=1$	2	3	4	5	6
1	Firewood + residues	0.40	0.40	0.35	0.21	0.11	0.11
2	Biogas	0.30	0.29	0.24	0.21	0.11	0.11
3	Wind	0.11	0.11	0.11	0.21	0.21	0.11
4	Solar	0.21	0.24	0.24	0.21	0.21	0.11
5	Water	0.21	0.40	0.24	0.21	0.11	0.11
6	Grid electricity	0.21	0.21	0.24	0.21	0.21	0.11
7	Kerosene	0.21	0.11	0.11	0.11	0.11	0.15
8	Petroleum products	0.11	0.11	0.11	0.11	0.11	0.24

The domestic sector shows 26.05% higher consumption than in the base case, while the industrial sector also shows similar increase of 29.81%. The commercial and services sector shows growth of 86.74%, the highest growth among all sectors.

Scenario V; Scenario IV + efficiency improvements scenario: The efficiency improvements inclusion in Scenario IV, by relatively simple efficiency improvement measures proposed, save over 29.91% of energy per year by 2015, when compared with Scenario IV (case without the improvements). Results of this scenario are listed in Tables 10.1–10.4, respectively.

Table 3.4
Talukwise estimated dung and hence gas yield per year

Taluk	Total (cattle + buffalo)		Number of persons requirement	Total population	Population that could use biogas (%)
	Tones	Biogas 000 m^3			
Ankola	61236.78	2204.52	17764.09	91310	19.45
Bhatkal	54289.01	1954.40	15748.62	129017	12.21
Haliyal	143466.90	5164.81	41618.12	94363	44.10
Honnavar	83563.83	3008.30	24240.92	145842	16.62
Karwar	56221.68	2023.98	16309.27	142845	11.42
Kumta	70862.93	2551.07	20556.53	134144	15.32
Mundgod	100492.53	3617.73	29151.74	77939	37.40
Sirsi	279067.32	10046.42	80954.26	152935	52.93
Siddapur	214814.91	7733.34	62315.36	94202	66.15
Supa	68347.05	2460.49	19826.70	99519	19.92
Yellapur	153493.92	5525.78	44526.84	81410	54.69
District total	1285856.86	46290.85	373012.46	1243526	30.00

Table 4.3
Assumed plant load factor and diversity factor

	Task							
	$j = 1$	2	3	4	5	6	7	8
Load factor	0.60	0.30	0.22	0.21	0.21	0.30	0.11	0.21
Diversity factor	1.80	1.40	1.20	1.20	1.20	1.00	1.20	1.20

Table 4.4
Cost per unit of energy used in the design

i	Resource	Task					
		$j = 1$	2	3	4	5	6
1	Firewood + residues	0.15	0.15	0.20	0.88	0.85	0.85
2	Biogas	0.25	0.35	2.75	0.40	2.75	2.75
3	Wind	1.30	1.30	1.30	1.30	0.45	1.30
4	Solar	0.20	0.15	0.45	0.74	1.65	1.65
5	Water	1.09	1.09	1.09	1.09	0.54	1.90
6	Grid electricity	0.79	0.79	1.30	0.70	1.30	1.90
7	Kerosene	0.65	0.65	0.85	0.35	0.65	1.30
8	Petroleum products	1.85	1.85	1.85	0.82	0.89	0.89

5.5. Sensitivity analyses

Sensitivity analyses help in identifying the role of a parameter or a set of parameters in optimal allocations. Parametric sensitivity analyses are carried out in order to analyse the effect of approximations. Sensitivity analysis is carried out for tasks by changing efficiencies of end use devices. If a source can supply either partially or fully requirements of more than one task or if the task has access to various resources for its energy needs, the type and number of transitions depend on various critical parameters, such as, unit cost of sources used by a particular task, efficiency of energy conversion of different energy paths, limits on the availability of resources if any, etc. The emerging allocation of resources for various tasks thus depends on the combination of values of critical parameters. Thus, sensitivity analyses give a clear picture as to how a single parameter or a combination of parameters influences optimal scenarios in regional energy planning exercise. This would help in a dynamic situation that may arise while implementing regional energy plan using the optimisation techniques. When the cost of biogas for cooking is taken as Rs. 0.35/m^3 and wood stove efficiency is around 10%, biogas is preferred for cooking. When efficiency of wood devices is increased in steps of 5%, it is noticed that, at efficiency greater than 30%, wood stoves are preferred for cooking while biogas enters lighting option. This shows that at low level of efficiency, wood stove is not economical, as biogas or electricity generated from hydro resources in a decentralised way is inexpensive. However, this scenario changes with increase in efficiency of wood energy devices beyond 30%. Hence, between 10 and 30% efficiency of wood devices, firewood supplements the available biogas in meeting the domestic needs of a region.

Table 5.1
Optimal allocation of resources (mkWh) for various tasks—minimisation of costs

Resources (mkWh)	Tasks						Total	Remnant Resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3268.78	20795.34	1271.72			1892.58	27228.42	9138.21	25.13
Biogas		346.23		2588.36			2934.59	0.00	0.00
Wind	33.02				172.53		205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.73	39.26			319.99	0.00	0.00
Kerosene				12.63		2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00
Total resources							38484.79		

Table 5.2
Optimal allocation of resources (mkWh) for various tasks—maximisation of efficiency (efficiency of F.W. + bioresidue devices: 10%)

Resources (mkWh)	Tasks						Total	Remnant Resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3039.13	20455.93	1271.74	43.96		2038.94	26849.70	9516.94	26.17
Biogas		2256.21		678.37			2934.58	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.02		2889.60	0.00	0.00
Grid electricity			280.73	39.26			319.99	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00
Total resources							38106.06		

Table 5.3
Optimal allocation of resources for various tasks—maximisation of efficiency and minimisation of costs (increasing efficiency of F.W. + bioresidue devices)

Resources (mkWh)	Tasks						Total	Demand–resource ratio	%
	1	2	3	4	5	6			
F.W. + bioresidue	2966.19	20977.32	524.11			2054.08	26521.69	9850.94	27.08
Biogas		346.23		2588.36			2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		531.25	1271.72		1086.63		2889.60	0.00	0.00
Grid electricity			280.74	33.26			314.00	0.00	0.00
Kerosene					9.04	6.10	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00
Total resources							37772.06		

Table 5.4
Saving by optimal allocation of energy sources for various tasks

	Energy (mkWh/year)	Cost (m.Rs./year)	Cost/kWh in (Rs.)	Energy saving (%)	Cost saving (%)	Demand–resource ratio
Original values	47623.00	18711.08	0.39			0.25
Minimisation of cost	38484.79	11930.28	0.31	19.19	36.24	0.31
Maximisation of efficiency	38106.06	12765.53	0.34	19.98	31.78	0.31

Note: m.Rs./year = million rupees/year.

5.6. *Validation*

The optimal allocations of resources for various tasks, based on maximisation of efficiency criteria for the base case scenario, were validated with the values compiled from various sectors for 2005. Computed values are comparable to the values compiled from various sectors for various resources. The level of accuracy was 99.4%, only the transport sector deviated from actual values.

6. Implementation

The framework of energy planning for a region, discussed so far, can become operational only after overcoming a large

Table 6.1
(Scenario I) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2005)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	2854.66	20740.93	1471.72	74.33		1948.06	27089.70	9276.93	25.51
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 6.2
(Scenario I) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2010)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3054.65	20634.10	1571.72	108.33		1930.90	27299.70	9066.93	24.93
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 6.3
(Scenario I) Optimal allocation of resources for various tasks—maximisation of efficiency (year 2015)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3295.66	20871.61	1671.72	143.33		1913.38	27895.70	8470.93	23.29
Biogas		2576.21				358.37	2934.58	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.73	39.26			319.99	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 6.4
(Scenario I) Uttara Kannada Scenario I-base case demand results for all fuels by sector (mkWh)

	2000	2005	2010	2015
Commercial, services, PL	11.17	13.10	14.72	16.75
Transport	100.57	115.52	127.99	152.35
Industry	1827.60	2300.56	2694.82	3063.81
Agriculture	3254.59	3350.74	3948.09	4848.80
Domestic	9981.52	10881.33	10982.38	11083.41
Total	15175.44	16661.26	17768.00	19165.11

PL: public lighting.

number of barriers and constraints, which usually come in the way of integration of energy supply programmes with the energy needs at the local level. These constraints include, among others, lack of mechanism at the local level to carry out assessment with the involvement of the potential beneficiaries, energy planning mechanism, project formulation and implementation. Proper coordination between the energy sector and the overall planning and development machinery is needed in a

Table 7.1
(Scenario II) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2005)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	2733.26	20124.76	1879.72	108.16		1925.05	26770.96	9595.68	26.39
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.73	39.26			319.99	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 7.2
(Scenario II) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2010)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3136.76	20236.35	1879.72	168.16		1893.47	27314.46	9052.17	24.89
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.73	39.26			319.99	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 7.3
(Scenario II) Optimal allocation of resources for various tasks-maximisation of efficiency (year: 2015)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	2908.35	20239.65	2479.72	272.16		1824.88	27724.76	8641.87	23.76
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.73	39.26			319.99	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 7.4
(Scenario II) Uttara Kannada "Scenario II" case demand results for all fuels by sector (mkWh)

	2000	2005	2010	2015
Commercial, services, PL	11.17	13.10	17.27	25.90
Transport	100.57	115.52	147.02	222.71
Industry	1827.60	2459.42	4084.14	8684.90
Agriculture	588.70	650.13	897.23	1449.31
Domestic	8941.56	9415.08	9852.32	11553.69
Total	11469.60	12653.25	14997.97	21936.51

PL: public lighting.

region for successful implementation of the energy plan. These and related issues are discussed in the following section.

6.1. Management aspects of energy planning

The current approach to planning in the energy sector does not offer any significant role to the district or local level institutions. Moreover, the coordination needed between the energy sector and the overall planning and development at district, taluk and village levels is missing. Although forestry planning is carried out by the district forest department, its most significant aspect pertaining to energy is extremely weak and receives very little attention in the planning exercises of the sector. The biomass situation in hilly taluks has, therefore,

Table 8.1
(Scenario III) Optimal allocation of resources for various tasks—maximisation of efficiency (year 2005)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	2636.41	20797.57	1171.72	78.56		1963.00	26647.26	9719.37	26.73
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 8.2
(Scenario III) Optimal allocation of resources for various tasks—maximisation of efficiency (year 2010)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3560.44	20474.03	1054.72	145.56		1901.03	27135.79	9230.85	25.38
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 8.3
(Scenario III) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2015)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3633.26	20705.61	1104.72	190.56		1963.00	27597.16	8769.48	24.11
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 8.4
(Scenario III) Uttara Kannada "Scenario III—transformation" case demand results for all fuels by sector

	2000	2005	2010	2015
Commercial, services, PL	11.17	13.16	14.79	18.15
Transport	100.57	110.43	117.35	137.81
Industry	1827.60	2319.34	2722.26	3351.92
Agriculture	3254.59	4090.77	5289.21	5745.25
Domestic	9981.53	9449.60	8617.78	8262.17
Total	15175.44	15983.30	16761.39	17515.30

PL: public lighting.

gradually worsened and has reached a point of crisis [47]. This deteriorating situation obviously demands immediate attention in two directions:

(1) Strengthening of local institutions for energy development.
(2) Promotion of coordination between institutions concerned with the energy development and overall planning at different hierarchical levels on the one hand and between institutions concerned with research and development on the other.

Table 9.1
(Scenario IV) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2005)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3089.66	21322.74	1843.72	78.17		1926.41	28260.70	8105.93	22.29
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 9.2
(Scenario IV) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2010)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3089.66	21596.39	1943.72	278.17		1852.10	28760.03	7606.60	20.92
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 9.3
(Scenario IV) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2015)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3389.66	21704.71	2525.72	478.17		1751.44	29849.70	6516.93	17.92
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 9.4
(Scenario IV) Uttara Kannada "Scenario IV—state energy norms" demand results for all fuels by sector (mkWh)

	2000	2005	2010	2015
Commercial, services, PL	11.17	17.02	34.70	97.17
Transport	100.57	122.48	170.81	274.71
Industry	1827.60	2501.30	4191.24	9121.04
Agriculture	588.70	787.92	1358.97	3293.33
Domestic	8941.56	9790.15	10504.56	12193.61
Total	11469.60	13218.87	16260.27	24979.86

PL: public lighting.

6.2. *Strengthening of local institutions for energy development*

As stated in the previous section, local government institutions at the district level (zilla panchayath) and below (village panchayath) can contribute positively in many ways towards energy planning and development. These include: (a) generation of energy databases, (b) promotion of community participation (c) extension and training, (d) dissemination of energy efficient devices and (e) implementation and sustainable management of locally available renewable energy resources [48].

Table 10.1
(Scenario V) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2005)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	2922.13	20431.35	1439.52	123.96		1932.74	26849.70	9516.93	26.17
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 10.2
(Scenario V) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2010)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	2824.35	20505.51	1716.99	247.96		1874.89	27169.70	9196.93	25.29
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 10.3
(Scenario V) Optimal allocation of resources for various tasks—maximisation of efficiency (year: 2015)

Resources (mkWh)	Tasks						Total	Remnant resources	
	1	2	3	4	5	6		mkWh	%
F.W. + bioresidue	3013.45	21245.24	1716.99	415.96		1817.05	28208.70	8157.94	22.43
Biogas		2576.21				358.38	2934.59	0.00	0.00
Wind					172.53	33.02	205.55	0.00	0.00
Solar	3742.94					1048.56	4791.50	0.00	0.00
Hydro		1481.58			1408.03		2889.61	0.00	0.00
Grid electricity			280.74	39.26			320.00	0.00	0.00
Kerosene					12.63	2.51	15.14	0.00	0.00
Diesel					31.38	68.61	99.99	0.00	0.00

Table 10.4
(Scenario V) Uttara Kannada "Scenario V: Scenario IV + efficiency case" demand results for all sectors (mkWh)

	2000	2005	2010	2015
Commercial, services, PL	11.17	16.09	29.54	70.34
Transport	100.57	116.43	147.51	203.58
Industry	1827.60	1985.62	2361.25	2993.89
Agriculture	588.70	600.39	632.61	703.61
Domestic	8941.56	8951.28	9355.71	9811.58
Total	11469.60	11669.82	12526.62	13783.01

PL: public lighting.

6.3. Generation of energy databases

The elaborate structure of the local government, which goes down to the village panchayath and its electoral wards can be effectively used for the generation of useful data. A simple methodology for obtaining information at both village panchayath and household levels has been demonstrated in this study. It may be pointed out that, besides collection of basic facts and figures, this kind of micro-level survey can also be used to assess problems and solutions perceived by local groups. This was particularly true of fuel wood for which the rapid rate of forest depletion, and not the limited area under forest, was conceived as a major problem or stress. This reckoning obviously is a positive factor and needs to be used effectively by involving representatives of such groups in the energy planning and development processes at the grassroots level. The household survey generated extensive data on energy which provided insights into energy consumption patterns (communitywise and landholding categorywise) use of cooking devices, possession of energy appliances, and the changing trends in energy use in the domestic sector. These surveys also indicated that the existing system of local government can be easily mobilised to build an effective energy information system for planning and development at the district and local levels without incurring any significant additional financial burden [48,49].

6.4. Promotion of community participation

The local government institutions also need strengthening to promote community participation in the planning and development process. These grassroots institutions, besides carrying out local projects with the involvement of communities within their jurisdiction, can also provide a powerful lobby through which communities can negotiate for services from sectoral agencies or departments of the government.

Unfortunately, the role of local councils in development efforts has been mostly underrated by planners, and is quite often overlooked in the implementation of energy projects, resulting in their failure to achieve the desired objectives. Energy plantation projects provide a case in point. It has been observed that, even when the political will is there and the funds are allocated, implementing a large-scale afforestation (plantation) campaign is an unexpectedly complex and difficult process. Planting millions of trees and successfully nurturing them to maturity is not purely a technical task, like building a dam. Further, tree-planting projects almost invariably get enmeshed in the political, cultural, and administrative tangles of a rural locality. The nature of their success, therefore, is largely governed by the intensity of community involvement through local government or other means. Central or state government stimuli in technical advice and financial assistance in such cases are ineffective (like some afforestation programmes in places like Yana in Kumta taluk) unless community members clearly understand why lands to which they had traditionally free access for grazing and wood gathering are being demarcated into plantations. Therefore, it is expected that they will view the project with suspicion or even hostility.

Also, the conservation efforts cannot succeed without strong commitment from the community. A major source of energy in the rural hill districts, such as Uttara Kannada, is biomass.

Slight improvements in the efficiency of energy use from this source can substantially improve the physical quality of life of the rural people in such districts without any increase, or even decrease, in the supply of primary energy. Adoption of appropriate cooking devices (improved cooking stoves) alone can bring a major change in this direction. Likewise, the replacement of dung fuel with biogas can provide both energy and manure on one hand and improve the quality of the environment on the other.

There is a need to distinguish the difference between subsistence energy requirements and energy required for economic development. As far as the subsistence energy requirement is concerned, the existing energy consumption pattern, with the major chunk being met through bioresources for thermal energy requirements, indicates the importance of intervention in this sector. The low conversion efficiency of energy devices (using bioresources) is a significant aspect in the context of designing energy intervention plans. Bioresource surplus taluks, such as, Sirsi and Siddapur are associated with high levels of consumption. In areas with surplus resources, the implementation of the efficiency measures have to follow an effort to convince and educate local people about the importance of efficient usage of resources. In the biomass scarce region, the significance of the interventions for fuel switching (such as solar energy for water heating, drying, etc.), improvement in end use efficiencies and augmenting supplies (through social forestry and energy plantations on barren land) are to be adopted [50,51].

6.5. Extension and training

Usually, energy programmes require a system by which end use devices, such as improved cook stoves (IC's) and biogas are disseminated in accordance with the programme objectives. Dissemination mechanisms become extremely important when the end use device is new to the user. Unfamiliar technology obviously raises a number of questions that can be answered only when the technology is successfully implemented and comprehensively evaluated. In order to strengthen the dissemination process, there is a need for rural energy centres. The purpose is to demonstrate the energy techniques that are suitable for local conditions and see that these techniques are practical and reliable from the farmers and locals' point of view [50]. The objectives of the Regional Energy Centres should be to

(i) study energy supply and consumption patterns to identify village needs,
(ii) demonstrate the use of efficient energy devices and disseminate, monitor and evaluate appropriate technologies,
(iii) augment the fuel supply situation through energy plantations and other decentralised means, and
(iv) analyse the impact of energy-related activities on the socio-economic development of the village and improvement of its environment.

Besides promotion of energy, the local panchayaths by themselves constitute a very strong extension network. Currently, the energy development agencies at the state level have little or no field staff. As a result, their rural energy programmes have suffered. The village panchayat can help fill this gap and can provide valuable assistance through quick dissemination and extension work.

6.6. Institutional coordination and energy development strategy

The implementation of rural energy programmes requires the involvement of a large number of official agencies working under different departments, private and public manufacturers, voluntary agencies, artisans, R&D institutions, village communities, social organisations and private individuals. This requires a considerable degree of coordination at the village, taluk and district levels [52].

At the district level, this function should be performed by the District Planning Officer who can also assist as a district level Project Implementation Officer. Besides coordination among the different tiers of planning institutions, there is a great need for networking R&D institutions, manufacturers and other concerned groups, e.g., community organisations and NGO's involved in rural energy planning and implementation. Finally, the success or failure of regional energy programmes/projects in a district will also be determined by strategies adopted and logistics provided. After a rural energy technology has been field-tested and found suitable for large-scale implementation in a district, the major task for its implementation will involve formulation of strategies based on the following factors:

(i) speed or rate of progress of programme implementation,
(ii) provision of funds and procedures for disbursing loans and subsidies,
(iii) making raw materials available for installation of energy transmitting devices,
(iv) creation of infrastructure for manufacturing energy equipment (it has also to be decided whether the public organisations should manufacture it or whether private entrepreneurs should be encouraged by providing incentives),
(v) R&D and maintenance networks to promote the design of energy equipment, training of artisans and mechanics for fabrication, installation as well as maintenance, and
(vi) monitoring and evaluation to facilitate timely feedback and assess the success of the programme.

7. Conclusions

Currently, bioresource is the single most important energy source in Uttara Kannada district, meeting more than 98% of the total energy needs. The over use of forest wood is creating serious ecological problems for the district in the form of deforestation, soil erosion and increased sedimentation. Uttara Kannada district mainly depends on noncommercial energy sources (96.23%), such as, firewood (78.071%), dung in the form of biogas (13.12%) and animate sources of energy (5.024%). While, commercial sources such as electricity (2.863%), kerosene,

diesel, petrol, etc., (0.904%) and LPG (0.0001%), constitute 3.767% of total energy consumption in the district.

The availability of wind resource is quantified, and it is found that coastal taluks have a good potential of the order of 30.64 (avg) $\pm$ 31.72 (S.D.) W/m^2 in Karwar and 26.50 (avg) $\pm$ 20.82 (S.D.) in Kumta. Availability of wind resources during pre-monsoon period, and local necessity of energy for industrial and irrigation purposes (for agriculture and horticulture) during this period make the exploitation of wind energy for mechanical and electrical energy purposes feasible and desirable in the coastal tract.

The electrical energy that can be harnessed by solar source is of the order of 191.43 million kWh by utilising 10% of wasteland, presently available in the coastal taluks of Uttara Kannada district. This constitutes about 65.1% of present electricity demand from various sectors of Uttara Kannada district. About 72% of solar energy is available during October to May period, when most of the agro-processing tasks such as drying (areca, cardamom, coconut, etc.) take place.

It is seen that about 1787.61 million units (mkWh) of electrical energy from hydropower sources in Aghnashini and 1079.17 million units (mkWh) in Bedthi river basin can be harnessed in an ecologically sound way.

Bioresources available in the region is of the order of 13,705.7 million units (mkWh) from forests, 318.07 million units (mkWh) in the form of agricultural residues and 825.97 million units (mkWh) as bioresidues from areca, coconut and cashew plantations.

Bioresource availability from livestock population is about 1.28 million tonnes, which is equivalent to 46.29 million cubic meter of biogas. This is adequate to meet the requirement of 30% of the total population.

End use efficiency study carried out in randomly selected households in some villages shows that there is scope for saving about 27.45% of fuel wood by switching over to energy efficient stoves.

If the entire district is looked at, bioresource supply appears to be diverse and sufficient in magnitude to comfortably sustain population pressure under the base case demand scenario investigated. As bioresource (fuel wood) enhancement strategies are pursued through social forestry, etc., complementary policies to promote technically feasible and cost effective improvements in the efficiency of end use equipment are needed.

The decision support system (DSS) approach is adopted for designing integrated regional energy planning for Uttara Kannada district. Integration is emphasised across all types of resources in the system and across all parts of the energy system (such as sectorwise energy demand, seasonal constraints in availability, environmental and economic impacts). Thus, the proposed integrated energy system is capable of meeting all energy needs from energy sources, taking into consideration the seasonal constraints in the availability.

There could be substantial saving in energy and overall cost, if efficient matching of resources and tasks is implemented. Optimisation based on the objective of cost minimisation, shows cost saving of 36.24%, and energy saving that could be of the order of 19.19%.

Optimisation carried out with the objective of maximisation of efficiency of '*ijk*' combination for all combinations, shows the energy saved to be about 19.98% and the saving in total cost as about 31.78%.

The scenario analyses show that potential renewable resources in Uttara Kannada district can meet the energy requirements of the district even under the assumption of high growth rates. That is, the relatively vigorous growth in energy demand in Uttara Kannada district can be accomplished without exceeding available resources in the region.

The process of energy planning at present, however, is a highly centralised activity, and district and local level institutions are not playing any significant role in the process. As a result, the energy crisis in rural areas, and particularly in hilly districts like Uttara Kannada, is not adequately reflected in national level planning.

In addition, energy development and conservation programmes are not being effectively implemented. This applies to a wide spectrum of programmes, ranging from the enhancement of social forestry to the introduction of energy-saving devices, e.g., improved cooking stoves. Hence, for energy plan to be optimal, there is a need to look at all sources available in the region and scrutinise the demand for energy services intensively.

This study has shown that the objective of effective implementation of energy planning cannot be achieved without decentralisation and community involvement. India is fortunate that it has a wide network of local government institutions at the district and lower levels. However, the system can be effective only if these institutions are assigned their due role.

The existing energy planning capability of the district is very weak. It is extremely important to amend this state of affairs by strengthening the energy planning and management capabilities from district to institutional level. This study has suggested some measures that can be adopted by existing institutions to generate an adequate database. This information can be used for effective energy planning. The study also showed that community participation, generated through union council (panchayath) involvement, can produce feasible projects within the broad goals set by district planning.

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